Designers and scientific knowledge production:

a case study of collaboration in Aalto University

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The societal role of universities and scientific research is being challenged by a new paradigm of knowledge production. Established structures and procedures are being pressured to reconfigure, facing the need to account for increasingly contextual, heterogeneous, transdisciplinary, and socially robust knowledge (Gibbons et al., 1994; Nowotny et al., 2001, 2003). Demand for reflexive and integrated research approaches has become more relevant in the face of global sustainability issues. Consequently, in many academic contexts, interest in multi-disciplinary collaborations is increasing. Among them, the collaboration between design and other disciplines is emerging. However, although a large body of research has investigated the role of design in business (e.g. Muratovski, 2015) and more recently in government and policy making (e.g. Malmberg, 2017), very little is still known about the potential role of design in scientific academic environments. Therefore, this thesis aims to provide an empirical account of design's contribution to research processes in the current framework of scientific practice.

Since its foundation, Aalto University has had the goal to foster a multi-disciplinary community with the mission of "shaping the future" to build a sustainable society (Aalto University, 2015). According to the University Strategy 2016-2020, the goal has been to solve complex societal challenges by combining knowledge from different disciplines, "science and art together with technology and business". Thus, Aalto University can be seen as a relevant context to observe emerging collaborations between disciplines. Most recently, various initiatives saw designers collaborating with scientists in the process of scientific knowledge production. Through a case study of such initiatives, this research explores practices of collaboration between designers and scientists. Qualitative data was collected through in-depth interviews with a group of 16 participants, composed of designers, scientists and research managers. The results outline various perceived contributions and related benefits of integrating design in the scientific research process. Aspects that act as barriers or facilitating factors to the collaborations are identified as well. Moreover, models from design management and interdisciplinarity studies are borrowed to observe the modalities of integrating and positioning design in the scientific research process and to relate them to the perceived benefits.

The study demonstrates that there is indeed potential in establishing design-science collaborations. It provides an initial frame to better understand and articulate the contributions and benefits of integrating design, such as connecting with the public, stakeholders, and the academic community or facilitating and challenging scientific research processes. This study reveals the need for further investigation into the qualities of "deeper" integration and the benefits associated with different models of integration. The findings also point to structural and cultural barriers that need to be addressed in order to establish successful collaborations between designers and scientists.

KEYWORDS *design, science, multi-disciplinarity, collaboration, knowledge production, scientific research*

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Introduction

1-1 Background and motivations

Over time, universities have established themselves as institutions of knowledge production, defining the notions of science and scientific discovery as we know them. However, a new paradigm is increasingly challenging established structures and procedures as well as the societal role of universities. Reconfiguration is needed if institutions want to adapt and account for what can be described as heterogeneous, contextual, transdisciplinary, and socially robust knowledge (Gibbons et al., 1994; Nowotny et al., 2001, 2003). Under this paradigm, scientific knowledge is being scrutinised, taking into account how knowledge is produced, represented and communicated, and redefining what is considered as valid knowledge and who is considered as a valid actor. Moreover, these new approaches to research, integrated and reflexive, are seen as necessary in facing global sustainability challenges (Hirsh Hadorn et al., 2006; Lang, 2012; Mauser et al., 2013).

Therefore, an increasing interest in multi-disciplinary collaborations can be observed in academic contexts. Among others, the discipline of design is taking part in collaborations within scientific academic environments. At the same time, while always retaining the constant tension between its abstract and material nature, design is moving towards more intangible contexts of application (Buchanan, 2001; Kimbell, 2011). This is one of the reasons why designers have been finding their way into business and management contexts, as well as, more recently, into government and policy making. Academic investigations about the role of design in these new domains are abundant (e.g. Muratovski, 2015; Malmberg, 2017), however, very little is known about the potential role of design in scientific academic environments. Hence, this thesis aims to increase the understanding of design's contribution to research processes in the current framework of scientific practice.

While undertaking my master studies, I have had the opportunity to work for various Aalto University departments. Given my background in visual communication and my previous experience working within academia, I was able to create data visualisations, concept graphics and illustrations for various researchers. As I worked with different groups, which ranged from electrical and chemical engineering, to land use and planning as well as arts, I started to reflect on my role as a designer in these collaborations and in the scientific process. I also got to know the people involved in the Materials Platform, one of eight Aalto Platforms aimed at promoting interdisciplinary action, by participating in their ARTSList program. It is thanks to these experiences and to the people I encountered that I was motivated to investigate the emerging initiatives facilitating design-science collaborations within Aalto University.

Aalto University is a relevant context to observe the collaboration between disciplines. Since its foundation, its goal has been to foster a multidisciplinary community, and its mission has been to "shape the future" in order to build a sustainable society (Aalto University, 2015). The University Strategy 2016-2020 states that solving complex societal challenges will be achieved precisely by combining knowledge from different disciplines. It is in this context that collaborations between scientists and designers have emerged.

In order to understand how design contributes to scientific research processes, I analyse and illustrate such practices of collaboration in Aalto University. Employing a case study methodology, I gather the perspectives and experiences of the people involved, interviewing 16 participants including scientists, designers and research managers. On these grounds, the contributions of design and the benefits of integrating it in a scientific academic environment are analysed. Additionally, I identify the perceived barriers and facilitating factors to collaboration.

This thesis demonstrates that integrating design in scientific research processes can, under the right conditions, contribute to knowledge production by improving reflexive, communicative and collaborative aspects. At the same time, the thesis identifies that factors such as disciplinary culture, organisational structures and lack of knowledge about design limit effective integration of design in science.

1-2 Research questions and goals

As stated above, I am interested in the roles of design within scientific research. The following question and goals guided my research within the specific case study context.

RESEARCH QUESTION

How does design contribute to research processes in the current framework of scientific practice?

RESEARCH GOALS

Research goal I — Illustrate emerging practices of collaboration between designers and scientists in Aalto University

Research goal II — Analyse the contribution of designers in such collaborations, identify common barriers and facilitating factors

1-3 Thesis structure

Chapter 2

The thesis is structured as follows: in chapter [2], I present an overview of the changing paradigms of knowledge production and different approaches to disciplinary integration in the academic context. As new paradigms put pressure on academic institutions, aspects of scientific research are being questioned. I further explore two of these aspects that are especially relevant for this thesis, as they intersect with typical design domains: communication and visual production of knowledge. I then describe the changing role of design as studied in different organisational contexts, from the private to the public sector, and finally I focus on the existing accounts of the integration of design in the process of scientific research.

Chapter 3

In chapter [3] I describe my research process, presenting the case study methodology and data gathering and analysis methods (i.e. in-depth interviews and thematic analysis). As I discuss the overall research approach, I also acknowledge my position as a researcher and my involvement in the topic.

Chapter 4

Chapter [4] is a description of the case study context and of the projects I analysed. A brief summary of the history and structure of Aalto University is provided, in particular taking into account the Aalto Strategy 2016-2020, followed by a detailed description of the instances of design-science collaboration that form the case study.

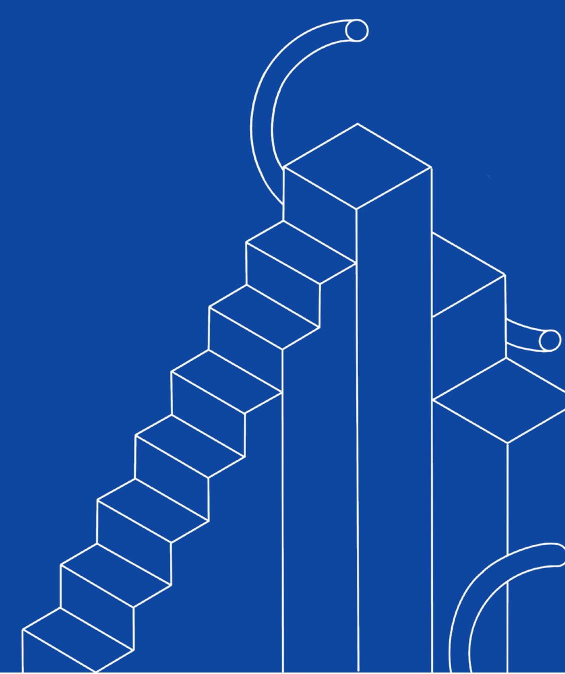
Chapter 5

In chapter [5] I present the findings organised by theme, according to the method of analysis. These themes are: the contributions of design to the collaborations, the benefits of integrating design in scientific research, the barriers and facilitating factors of collaboration, and finally types of design integration, described using two models.

Chapter 6 To conclude, in chapter [6] I summarise and discuss the findings. I reflect on their relevance to my initial question as well as their implications for research and practice.

2

Literature review



In this chapter I summarize key arguments from sociology of science, design and design management literature in order to contextualize this thesis. I approach the literature review from two main angles: knowledge production and design integration.

Knowledge production

Subchapters [2-1] and [2-2] tackle scientific knowledge production in order to set the background for this thesis and to understand the wider debate and societal relevance. In [2-1], I address the academic conversation around the changing landscape of scientific knowledge production. This includes an overview of new modalities of knowledge, particularly of what is referred to in sociology of science as Mode 2 (Gibbons et al., 1994). The interaction between disciplines emerges as a crucial aspect of Mode 2, therefore different approaches to disciplinary integration are described. Moreover, I discuss the relevance of Mode 2 of knowledge production for tackling complex contemporary issues, especially in sustainability research.

In light of changing paradigms of knowledge production, the scientific research process has become increasingly reflexive and various facets are being scrutinised, such as *how* knowledge is produced and *who* is involved. In [2-2] I further explore two of these aspects which are particularly significant in the context of this thesis: communication and representation. These have been chosen as they could likely benefit from design's intervention, being at the intersection with some of design's typical domains. The first section looks at the relationship between science and the public through the lens of communication. I present how modern scientific institutions have approached communication over time, through concepts of scientific literacy and an underlying assumption of a lack of knowledge in the public. In the second section, I discuss the role of visualisation in science to establish its relevance and validity as a form of scientific knowledge production.

Design integration

The second theme, found in subchapters [2-3] and [2-4], is the one of design integration in different organisations. This literature review provides a direct reference for the empirical part of this thesis, which explores the integration of design in academia. In [2-3], I introduce design and its evolving position within organisations. First, I discuss various accounts of design and design thinking. Next, the role of design in the context of business and government is introduced, along with a model to assess the integration of design in organisations. Finally, in [2-4] I review the current literature on design-science collaborations. I introduce studies of the ways in which designers can contribute to scientific research, mostly from the point of view of graphic and industrial design. A final section is dedicated to existing models used to assess collaborations between design and science.

2 - 1 Modalities of knowledge production

MODE 2 OF KNOWLEDGE PRODUCTION

Traditionally, the production of knowledge has been associated with a Newtonian ideal of scientific discovery, characterised by the dominance of theoretical or experimental science. Typically, this type of knowledge production is what is meant by "science". Universities are some of the institutions where it is practiced, in autonomy, by scientists within their disciplinary context. However, it has been argued that new modalities of knowledge production have been emerging in the past decades and the process of research is being transformed as a result. These influential ideas were first introduced by Gibbons et al. (1994) in their book *The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies* and further discussed notably in *Re-Thinking Science: Knowledge and the Public in an Age of Uncertainty* (Nowotny et al., 2001) and "'Mode 2' Revisited: The New Production of Knowledge" (Nowotny et al., 2003). The authors use the term "Mode 1" to indicate the norms and values that characterise what they call "the old paradigm of scientific discovery". Under said paradigm, the Newtonian model must be followed in order to produce legitimate knowledge. Alongside Mode 1, they introduce the emerging "Mode 2", a new paradigm of knowledge production. Mode 2 refers to knowledge which is produced within a broader context; it operates within its context of application and therefore it transcends disciplines, as problems are not set in disciplinary frameworks.

Based on the above mentioned sources, Mode 2 can be better described through five properties: (1) Context of application, (2) Transdisciplinarity, (3) Heterogeneity, (4) Accountability and reflexivity, and (5) Quality control.

(1) Knowledge is increasingly generated in contexts of application. The context of application describes the complex social and economic environment in which the research process takes place. Such knowledge is therefore diffused throughout society, or in other words it is "socially distributed knowledge".

(2) The second quality is "transdisciplinarity". Transdisciplinarity is not the accumulation of knowledge from different disciplines; according to Gibbons et al., it is instead a distinct framework in which various perspectives and methodologies, both empirical and theoretical, are engaged and integrated.

(3) In Mode 2, typologies and sites of knowledge production are diverse. Many new organisations generate knowledge alongside universities and industry, such as think tanks, consultancies, activist groups, and research centres.

(4) Instead of a one-way process of transfer, knowledge production is a dialogue between actors in society. Individuals and groups can become active agents in setting research priorities, as well as defining problems and finding solutions.

→ **Table 1** Comparison between Mode 1and Mode 2. Based on Gibbons et al. (1994)

Mode 1	Mode 2
Problems are set and solved in the academic community	Knowledge is carried out in a context of application
Mono-disciplinary	Transdisciplinary
Homogeneity	Heterogeneity
Hierarchical, conservative	Heterarchical, transient
Autonomous	Socially accountable, reflexive

Consequently, the awareness of the way in which scientific knowledge can affect the public has rendered its practitioners more "reflexive".

(5) Finally, new forms of quality control emerge in Mode 2. As more actors and interests are involved, new criteria and questions arise in order to assess what is "good science". Therefore, to determine "quality" is increasingly more complex, as multiple definitions need to be taken into account.

Gibbons and his co-authors discuss, among other topics, the implication of Mode 2 for universities. They argue that there is a need for reconfiguring institutions, which are especially challenged by the new paradigm. Universities' structures and procedures have been established to facilitate the traditional mode of knowledge production and therefore can be resistant to change. For example, it is difficult to set up structures that account for transdisciplinarity within a system built on disciplinary organisation. In such a system, disciplinary learning is seen as the way to gain competence. Moreover, in the process of training, people come to adopt a disciplinary identity, characterised by a world-view. They learn what is to be considered a problem, alongside how to frame it and solve it. Therefore, in order to engage in multi-disciplinary processes, practitioners have the difficult task to balance their disciplinary identity with what Gibbons et al. call "transdisciplinary competences".

Nowotny (2003) also discusses the implications of Mode 2 for the role of experts and expertise in society. She argues that expertise is "transgressive", as it "must address issues that can never be reduced to the purely scientific and purely technical" (p.152) and it is also interfacing with an audience which is never constituted by experts only. The need to widen the notion of expertise is discussed in relation to the larger demand for legitimacy and accountability. However, greater accountability can also be achieved by focusing on *how* expertise operates, not only on *who* or *what*. She cites the concept of "technologies of humility" (Jasanoff, 2003) to complement traditional predictive approaches. Jasanoff voices the need to "make apparent the possibility of unforeseen consequences; to make explicit the normative that lurks within the technical; and to acknowledge from the start the need for plural viewpoints and collective learning" (p.240). According to Jasanoff (2003), the four key points for developing technologies of humility are framing, vulnerability, distribution and learning, or: "what is the purpose?; who will be hurt?; who benefits?; and how can we know?".

Moreover, Nowotny introduces the concept of "socially robust knowledge", stating that reliable knowledge, within a disciplinary context, is not sufficient. In Mode 2, knowledge is viewed in the broader societal context, therefore a larger community is challenging it. There are three fundamental aspects to socially robust knowledge. The first is that its validity is tested also outside the laboratory, in the real-world context with its political, cultural, economic and social implications. Second, the notion of expertise is expanded to include an extended group of actors, experts, users, and lay people. Different knowledge dimensions are brought together and connected. Finally, it is robust as a consequence of being tested multiple times, as well as expanded and modified.

In the conclusion of the 1994 book, *The New Production of Knowledge*, the authors list six future issues which, in their opinion, would likely become underlying trends. These are still relevant today, including questions about the future of funding in an increasingly diverse system and the future of disciplinary identities in relation to transdisciplinary competences.

APPROACHES TO DISCIPLINARY INTEGRATION

First, it is important to define the concept of disciplinarity. In the first universities, knowledge domains were contained under few areas and academics were versatile. However, over time, domains have become more and more specialised, consequently being divided in disciplines and subdisciplines. Yet, the establishment of disciplines under departmental structures in universities is a fairly new phenomenon, consolidated at the end of the nineteenth century (Max-Neef, 2005). Ben-David (1971, cited in Janssen & Goldsworthy, 1996) states that a discipline is characterised by the choice of topic being defined internally, with the objective of advancing disciplinary understanding. A discipline provides the researcher with an identity, each one having its own organisational structure and culture, professional standards, study programs and publication outlets. Another characteristic is the principle of scientific reduction, according to which the focus is restricted to predefined units of analysis (Janssen & Goldsworthy, 1996).

As mentioned above, Gibbons et al. (1994) argue that knowledge production also takes place outside the boundaries of disciplines, in the interstices and interfaces and in relation to different expertises. In their view, the demand for this type of knowledge comes from society, as public issues cannot be tackled through a single perspective. This idea has become more and more relevant, as seen in global and complex problems such as climate change, water scarcity, or migration. Therefore, there is an increasing need and drive for integrated research approaches, able to provide holistic and systemic views. However, there is also wide variety when it comes to integrated approaches and their definitions. I adopt Keskinen's (2010) definition of "multi-disciplinarities", an umbrella term that includes four types of integration: (1) multidisciplinarity, (2) crossdisciplinarity, (3) interdisciplinarity, and (4) transdisciplinarity, as summarised below.

(1) ***Multidisciplinarity***
This approach can be considered the simplest one. It entails tackling a topic from multiple disciplinary perspectives, however, research is carried out separately. The methods used are specific to each discipline, as well as the knowledge produced.

(2) ***Crossdisciplinarity***
In a crossdisciplinary approach, a topic is also viewed by different disciplines. In this case, however, the knowledge domains interact with each other and cross their boundaries. Keskinen, citing Mäki (2007), describes two types of interaction: egalitarian and non-egalitarian. In the first instance, disciplinary perspectives merge with one another, while in the second approach one discipline is dominant over the others. In many situations, a non-egalitarian form is preferred, therefore the point of view of a certain discipline is primarily used to analyse a topic.

(3) ***Interdisciplinarity***
Interdisciplinarity integrates methods, concepts and theories from different disciplines to create a comprehensive and systemic view of a topic. This approach is problem-based and application-oriented; it strives to address issues by choosing

the most appropriate methods without being constrained by disciplines. New conceptual and theoretical identities can be created. For example, in an interdisciplinary team experts would define a research problem and plan together in order to tackle it as a team.

(4) ***Transdisciplinarity***
Transdisciplinarity differs from other forms of collaboration as it transcends singular disciplinary perspectives, fusing disciplines together rather than mixing them. Therefore a novel framework for knowledge production is created. Similarly to interdisciplinarity, it is closely connected to the context of application and it can adopt theories and methodologies which are not associated with a specific discipline. Transdisciplinarity is one of the fundamental characteristics of Mode 2 knowledge production. It involves the collaboration between different actors and sectors of society, therefore challenging and widening the notion of expertise.

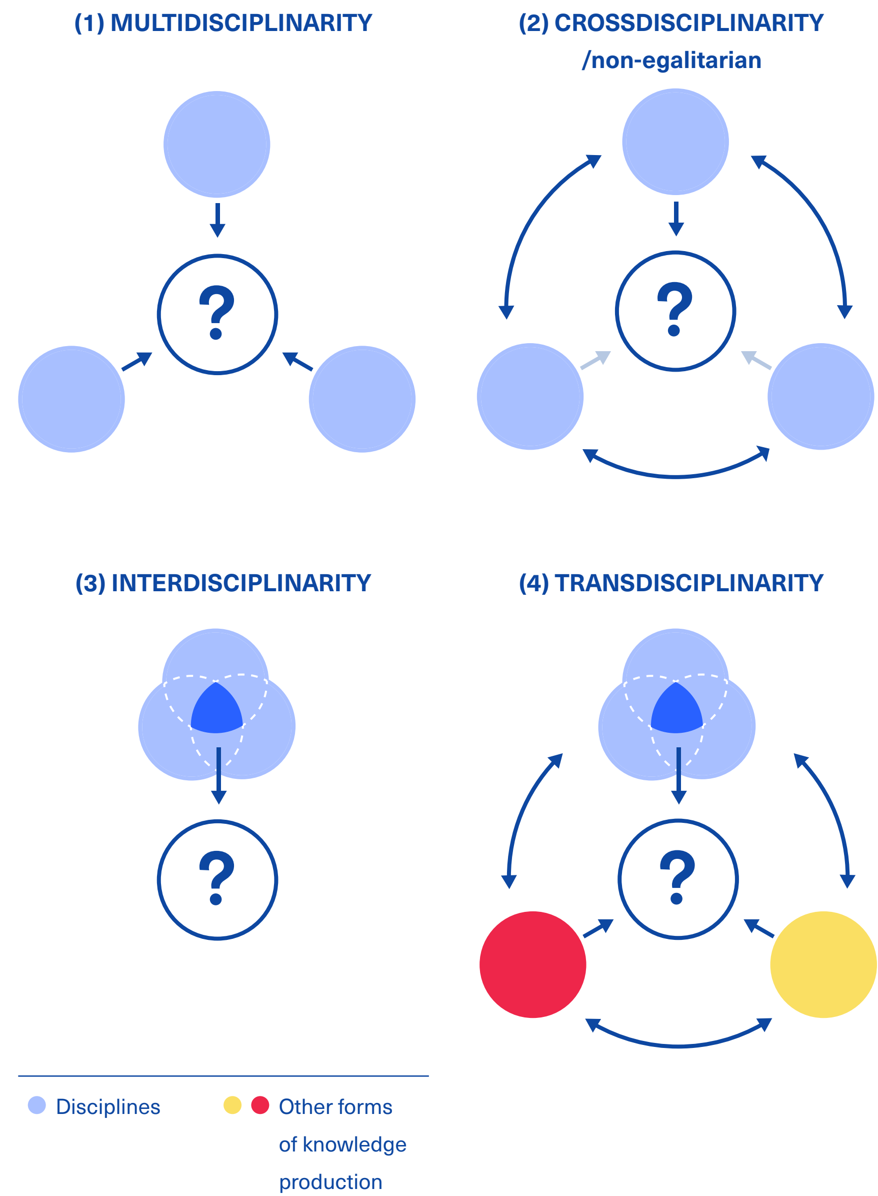


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Fig. 1
Visualisation of the four types of multi-disciplinarities. Based on Keskinen (2010)

KNOWLEDGE PRODUCTION IN THE AGE OF GLOBAL SUSTAINABILITY ISSUES

A public issue defining our times is the one of sustainability. Human activities are causing planetary environmental changes, exerting pressure on Earth-system processes and undermining the conditions for humanity to thrive (Rockström et al., 2009). In light of these concerns, science and knowledge production are especially compelled to respond and change. In the article "A New Climate for Society" (2010), Jasanoff describes the unique challenges that climate change poses to our ways of understanding. In her view, science represents reality, rather than mirroring it. She argues that in such processes of representation, science tends to create an "impersonal, apolitical and universal imaginary" (p. 233) of climate change which is in contrast with the subjective and situated experience of individuals. Therefore, conflicts arise when techno-scientific systems are far removed from their contexts of application, showing tensions between specificity and abstraction, subjectivity and objectivity. These polarities, arguably always characteristic of scientific knowledge production, are exacerbated in the case of complex contemporary issues like climate change. An explanation is that this is a phenomenon which "repeatedly slips out of the conventional boundaries of sense-making" (p.245); or using Morton's concept, it is a "hyperobject" (Morton, 2013):

> "It is 'viscous' — whatever I do, wherever I am, it sort of 'sticks' to me. It is 'nonlocal' — its effects are globally distributed through a huge tract of time. It forces me to experience time in an unusual way. It is 'phased' — I only experience pieces of it at any one time. And it is 'inter-objective' — it consists of all kinds of other entities but it isn't reducible to them." (Morton, 2015)

How can communities and individuals make sense of these hyperobjects? How can meaning be created and the issues around them be tackled? It is in this regard that qualities of Mode 2 knowledge production become especially relevant, as well as concepts like technologies of humility and socially robust knowledge. In the policy and research landscape, it can be observed how some of these approaches have been discussed and promoted in relation to sustainable development. The 1992 United Nations Conference on Environment and Development held in Rio de Janeiro can be seen as a milestone for the discussion on the role of research in addressing society's issues. Since the late 1990s, sustainability research, or sustainability science, has been established as a "problem-driven and solution-oriented field" (Lang et al., 2012, p. 40). Overall, there has been an increased acknowledgement of the need for transdisciplinary and integrated approaches to knowledge production for sustainability (Hirsch Hadorn et al., 2006; Lang et al., 2012; Mauser et al., 2013), calling for "participatory procedures involving scientists, stakeholders, advocates, active citizens, and users of knowledge" (Kates et al., 2001, p.641, quoted in Lang et al., 2012).

2 - 2
Communication and visualisation in science

SCIENCE COMMUNICATION AND PUBLIC UNDERSTANDING OF SCIENCE

The communication of science became a relevant topic in the nineteenth century, as scientific research entered the public sphere along with new inventions and institutions. Science communication as a term can loosely refer to any kind of public communication of scientific topics to a lay audience, including journalism, institutional documents, exhibitions, and movies. However, science communication as the object of academic research is a fairly new discussion, which began around forty years ago.

In the words of Burns et al. (2003), science communication "aims to enhance public scientific awareness, understanding, literacy and culture" (p.198). While it is indeed concerned with communicating science, it also aims to provide tools and skills to empower the actors involved to engage in a more effective dialogue (Burns et al., 2003). In the past decades, the discipline has been growing considerably, generating various fields of inquiry. One of them is the Public Understanding of Science (PUS), whose birth can be traced to the publication of the Bodmer Report by the British Royal Society in 1985. PUS has been largely concerned with the so-called "deficit model", the assumption that there is a lack of scientific knowledge among the public, causing societal conflict.

The term deficit model emerged during the 1980s when social scientists started using it to describe the paradigm behind most of science communication until then. In fact, since the 1960s, researchers have acknowledged the existence of a societal conflict over science, consequently investing effort into understanding the public's perception. They assumed that the reason behind society's conflict over science and technology is a lack of knowledge: the public is ignorant and therefore might be skeptical or unfavourable toward science. For this reason, most endeavours have been focused on education, in which scientists communicate the "facts" to the lay public (Ahteensuu, 2012).

A widely influential definition of "science literacy" was introduced by Miller (1983), whose indicators for literacy, based on previous work done in the 1960s, have been adopted by many western institutions for national surveys, including the US National Science Foundation. Miller's definition is further summarised by Bauer et al (2007) in four elements: (1) knowledge of textbook facts, (2) understanding of scientific methods, (3) a positive attitude towards science and (4) the rejection of superstitions. As it can be deducted from the aforementioned definition, scientific knowledge is understood in terms of objective "textbook" facts and has consequently led to many efforts to strengthen and improve science education.

Another implication of the definition is the idea that knowledge equals a positive attitude towards science. Therefore, if someone is sufficiently literate, they can't possibly be hostile towards scientific institutions or technological innovations. In other words, "the more you know it, the more you love it" (Bauer et al., 2007, p. 83).

DEFICIT MODEL OVER TIME

Lack of	When		Solution
Knowledge	1960s	→	Education, Literacy measures
Positive attitudes	1980s	→	Attitude change, Knowledge-attitude
Trust in experts	1990s	→	Participation, Dialogue

↑ **Table 2** Evolution of the deficit model. Based on Bauer et al. (2007)

These notions reflect the underlying assumptions present in much science communication since the 1960s: science is "sufficient" while the public is "insufficient" (Sturgis & Allum, 2004).

Later on, however, the publication of the Bodmer report and the emergence of PUS contributed to a distinction between knowledge and attitude. The concept of "deficit" evolved, and now refers to the lack of positive public attitude rather than knowledge, and the focus of academic research within PUS moves to the relationship between the two (Bauer et al., 2007; Sturgis & Allum, 2004). Although the focus has shifted, the assumption of a deficient public is still very much present.

The deficit model has attracted much criticism over the years. It is argued that it creates a bias in the scientific community: the public is always ignorant and, therefore, cannot be trusted. The bias activates a vicious circle which, according to Wynne (1992), is an expression of what he calls "institutional neuroticism", meaning institutions being excessively concerned over their trustworthiness. With his influential study about the interaction between English sheep farmers and nuclear scientists during post-Chernobyl times, Wynne is one of the major critics of the deficit model. He claims that while scientific knowledge is conventionally interpreted as "objective and context-free" it is instead embedded in social structures and identities. The study builds on a more recent contextualist notion, which emerged in the 1990s, of public understanding being rooted in trust and credibility of the scientific actors. However, Wynne (1992) shifts the focus to "the social relationships, networks and identities" (p.282) which generate the aforementioned trust and credibility. In his view, these are not inherent concepts, but relational terms which need to be traced back to the relationships between the actors.

After Wynne, decades of further research has widely criticised the deficit model. In this criticism, the issue of trust has still been at the core but the scientific experts themselves have become the object of the critique (Bauer et al., 2007). For example, Nisbet and Scheufele (2009) argue that by adhering to the deficit model, communication has merely become a process of transmission. Furthermore, when this process fails and the public is blamed for its ignorance or the media for its work, this might have the negative and unintended effect of additionally alienating key audiences. In the case of climate change, Hart and Nisbet (2012) further argue that science communication might even increase public polarisation over the subject, resulting in a boomerang effect.

In order to rebuild public trust and move beyond the deficit model, various solutions have been proposed. Generally, they revolve around the idea of public engagement and participation (Bauer et al., 2007). More specifically, Nisbet and Scheufel propose a series of directions forward in their 2009 article "What's next for science communication? Promising directions and lingering distractions". For example, they advocate for graduate training and interdisciplinary programs in order to educate the scientists themselves in communication and the issues regarding scientific topics. Moreover, they place much emphasis on the creation of a dialogue in place of the transmission process mentioned above, one which can connect to people's values and move beyond elite audiences (those already rich in information).

On the other hand, other research argues that the deficit model, although it certainly is a simplification of a more complex reality, has a certain degree of validity and should not be disregarded as a whole. For example, Sturgis and Allum (2004) bring attention to how the critique of the deficit model has stigmatized quantitative methods of research. They propose instead to re-evaluate the model and to bridge deficit and contextualist perspectives as both valuable and not mutually exclusive. Moreover, Allum et al. (2008) found in their cross-cultural study a small but positive correlation between attitudes and knowledge in regard to science, giving some ground to the saying "to know science is to love it".

Although there is much academic debate about this topic, it appears that moving beyond the deficit mindset can be very difficult in practice (Ahteensuu, 2012). Bubela et al. (2009) point out that "despite increasing attention to new directions in public engagement, a still-dominant assumption among many scientists and policymakers is that when controversies over science occur, ignorance is at the root of public opposition" (p. 514-515).

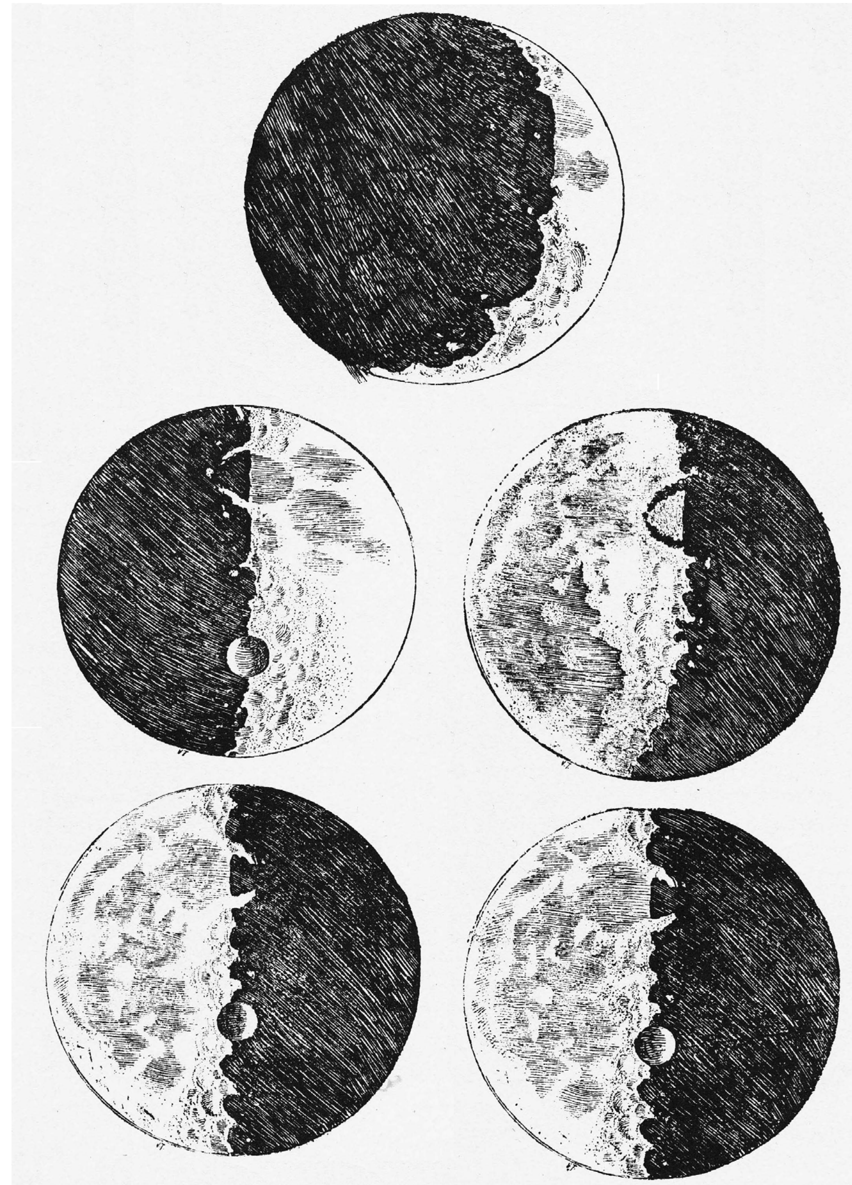
VISUAL PRODUCTION OF KNOWLEDGE

Visualisation is a key aspect of design activity, often acting as a "thinking tool" (Seitamaa-Hakkarainen & Hakkarainen, 2000) and playing a central role in disciplines such as graphic or information design. Therefore, in order to understand how design might contribute to scientific research, it is necessary to first briefly discuss the place of visualisation in science.

In the discourse around knowledge, very little is said about the visual form of knowledge production. However, figures and images have always been an integral part of research practices, dating back to ancient Egypt and later Greece, as early as 4000 B.C.. During the Renaissance, Galileo, who studied fine arts as well as science, used illustrations to support his argument for a heliocentric system (Rolandi et al., 2011). Nowadays, figures are often at the top of research papers and are one of the first parts reviewed by peers.

Despite this centuries-long tradition, the visual form has been historically disregarded in comparison to the written form. It has been treated as decoration, as intellectually inferior (Cairo, 2013). This notion can be traced back to ancient Western philosophy, as Greek thinkers such as Plato and Parmenides held great mistrust in the senses (Arnheim, 1969 cited in Cairo, 2013). While this way of thinking continues today, in the last couple of decades there has been a rising interest in visual representations as a research subject and as communication and sense-making tools (Bertschi et al., 2013; Cairo, 2013; Scagnetti, 2011).

The newfound interest is reflected in a variety of new



→ **Fig. 2** Galileo's sketches of the moon from *Sidereus Nuncius* (Galileo Galilei, 1610) disciplines and practices, stemming from different fields. Information design, data visualisation, and knowledge visualisation are only some of the disciplines that have been recently established at the intersection of fields such as computer science, statistics, knowledge management, design, journalism, and cartography. Consequently, each discipline employs different terminology and definitions, sometimes overlapping or even contradicting. For the purpose of this thesis I will not refer to any one specifically. I will, however, use "visualisation of knowledge" as an umbrella term to refer to the process of producing or representing knowledge in visual form. "Visual artefacts" or "visual objects" will be used to refer to the outcomes of said process.

Moreover, while the idea that visual artefacts are rhetorical devices and political in character is not new (Law & Whittaker, 1987), in recent years researchers have been again making the case for discussing the use of visual languages from a critical and humanistic perspective (Drucker, 2014; Halpern, 2015). For example, Drucker (2010) argues that the idea that facts are "pure" and exist outside of their visual representation is problematic. In this view, the representation is inherently "flawed", as it will always be an approximation of the facts, which are pure. She advocates instead that visualisation should be recognised as a valid form of knowledge production and that the relations between *what* is communicated and *how* should be acknowledged.

The book *Image politics of climate change* (Schneider & Nocke, 2014) is an example of how the humanistic perspective of visual cultures can be applied to scientific knowledge production. In the introduction, editors Schneider and Nocke state that climate change is a scientifically constructed object and climate change knowledge is mediated knowledge. Since the spatial and temporal scales of such phenomena are too vast to be experienced directly, they argue that visual objects are the only and crucial way to acquire such knowledge. Climate images have then an epistemic purpose, as they are constructing our understanding of the phenomena. At the same time, they are political as they are produced with normative purposes, evaluating certain outcomes as desirable or undesirable. They have therefore the potential to influence people's opinion and decisions, to be a catalyst for action.

A timely example of the normative and epistemic nature of visual knowledge is the so-called "Flatten the Curve" graphic. As I am writing this thesis, most of the world is facing a viral outbreak. In many countries, including Finland, the population is practicing social distancing to prevent COVID-19, or the disease caused by a novel coronavirus, from overwhelming their healthcare systems. This is a crucial time for knowledge production across sectors of society and collaboration between science, policy and civil society stakeholders. As a visual artefact and as a concept, Flatten the Curve finds itself at the centre of this global crisis. Its core message is that preventative measures (i.e. social distancing, washing hands) can slow down the spread of the disease in order to avoid the exhaustion of the finite capacity of national healthcare systems. The visual object, which originated as a figure in an academic paper, is constructing our knowledge about the dynamics of the pandemic as well as clearly suggesting what is the desirable behaviour to adopt. Visualisation researcher Robert Kosara describes it as “actionable”. The graphic, which can be traced back to as early as 2007, has then been adapted by private and public media outlets[1], playing a decisive role in this time of crisis.

[1]
Some notable articles that investigated the evolution of the graphic are by the Washington Post (Stevens, 2020), Fast Company (Wilson, 2020) and visualisation blog eagereyes (Kosara, 2020)

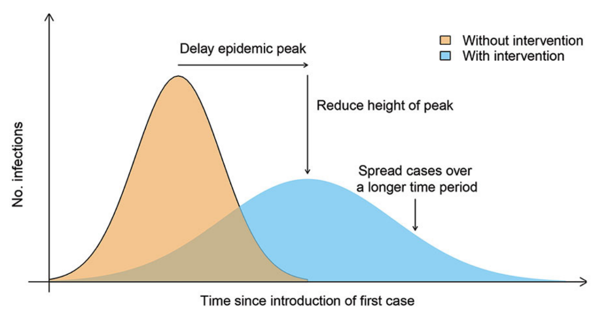


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Fig. 3
Two curves are combined in one chart, pre-published paper (Fong et al. 2020, Figure)

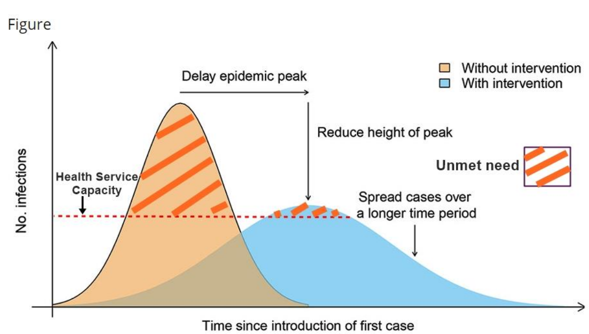

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Fig. 4
The line showing the Health Service capacity is added (Dalton et al. 2020, Figure 1)

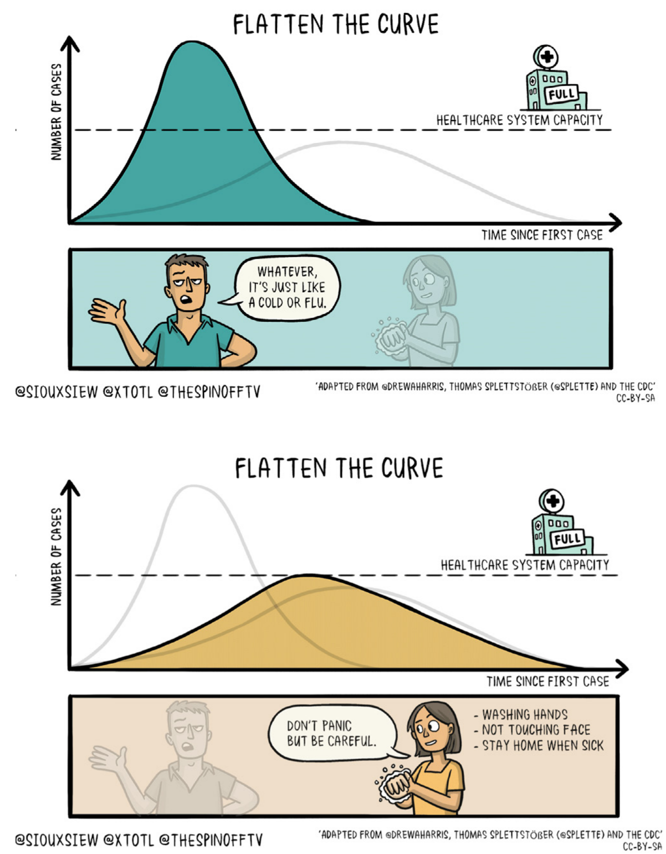

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Fig. 5
The concept is reinterpreted in the “Flatten the curve” animated illustration in New Zealand publication *The Spinoff* (Wiles & Morris, 2020)

2 - 3
Design in organisations

DEFINING DESIGN

In order to understand the relationship between design and private and public sector organisations, it is first necessary to briefly address design itself as a discipline. This is not an easy task, as design is a fragmented, evolving domain. In the following paragraphs I will provide a brief summary of some accounts, albeit not an exhaustive one, and I will touch upon the popular concept of "design thinking".

Despite some form of design arguably being present at some time in all parts of the world, it is with the Industrial Revolution in Western societies that it has emerged as a profession (Margolin, 2005). Design's history is then intertwined with the rise of mass production and a neoliberal economic model (Julier, 2017). Moreover, while establishing itself as a discipline with its own culture, design has always drawn from other practices and research cultures, especially in art, science and technology (Lawson, 2006). Lawson (2006) argues that it is a difficulty as well as a fascination of designing to have to embrace different types of knowledge. At the same time, thanks to such a fragmented and complex background, there is no unified and single definition of design.

Over time, many scholars have attempted to conceptualise design. Kimbell (2011) identifies a tension between two concepts which can be observed in all pursuits and remains relevant today. This is the tension between the material, tangible aspect of design and the abstract nature of the practice. She exemplifies these two concepts with Alexander's view of design as giving form to physical things (1971) in contrast with Simon's belief that design's task is to create a desired state of affairs (1969). Although such tension is always present, it seems that design has been, in the last decades, increasingly concerned with the abstract aspect, especially with how designers think.

Lawson (2006) has reflected on whether there is a common process among various design domains and individuals. He argues that design thinking is a skill and outlines models of designing which are groups of activities and skills (formulating, moving, representing, and evaluating). In his view, the purpose of design is problem-solving. Similarly, Cross (1982) is concerned with what he calls "designerly ways of knowing" and he observes a problem-solving attitude as well. He often compares it to science, which is analytic and relies on pattern recognition, while design strives for pattern synthesis and is constructive, normative, and creative. Cross also specifies that a designer's problem-solving approach is solution-focused, rather than problem-focused, and that such problems are "ill-defined" and "wicked". Interestingly, he connects the abstract and the material by stating that designers "translate abstract requirements in concrete objects", therefore seeing objects as a form of knowledge.

Buchanan (2001) has also attempted to define design. Compared to Lawson and Cross, who frame design thinking as a cognitive style, Buchanan approaches design thinking as a general theory of design (Kimbell, 2011). While stating that one of design's greatest strengths is that it is not settled on a single definition, he also recognises the value of definitions in advancing inquiry. Therefore, he goes on to propose the following: "Design is the human power of conceiving, planning, and making products that serve human beings in the accomplishment of their individual and collective purposes" (p.9). To define the term "products", he refers to four orders of design. Most interestingly, these four orders move from a material to an abstract focus, from symbol and things to actions and thoughts. This conceptualisation denotes the shift of the discipline towards applying design thinking to intangible environments and systems.

Perhaps the more widely known account of design thinking is the one that originated at IDEO, a prominent design consultancy. Brown's *Change by Design: How Design Thinking Transforms Organisations and Inspires Innovation* (2009) helped to popularise the concept of "design thinking" as an organisational resource, as a tool for innovation and for solving society's problems. A characteristic of this approach is the emphasis on design as "human-centric", following an iterative process which starts with empathising with the user. Kimbell (2011), a prominent critic of design thinking, argues that this approach is paradoxical as it lacks reflexivity and still sees the designer as the main agent in designing. A related concept of design thinking figures in another popular book, *The Design of Business: Why Design Thinking is the Next Competitive Advantage* by Martin (2009). Design thinking is seen as a competitive tool for organisations and is adopted as a concept within managerialist discourse. These publications, despite lacking a wide research base, are the ones responsible for disseminating this specific idea of design thinking through various public and private sectors of society (Kimbell, 2011). The ubiquitous idea, which is not always well understood, seems to be a universal approach that everyone can learn or apply. In Kimbell's words, "decoupled from any one field or discipline of design, design thinking is meant to encompass everything good about designerly practices" (2011).

DESIGN AND BUSINESS

Following the dissemination of the concept of design thinking and the rise of the "knowledge economy", many types of organisations have begun to adopt design as an innovation and problem-solving tool. Although design and business have always been connected, recently the attitude of corporate cultures has been shifting. Muratovski (2015) has studied this phenomenon and identifies key trends. First of all, design is increasingly seen as a strategic business resource; major corporations are investing in building in-house design capabilities and promoting designers to executive and leadership roles. Moreover, designers are perceived to add value to emerging businesses, a trend that can be seen in the startup sector and in venture capital. Finally, global organisations (UN, World Bank) and leading foundations (Rockefeller, Bill & Melinda Gates) are employing design in the context of international development, sustainability and social innovation.

The topic continues to be addressed in recent reports such as *The Design Economy 2018* by the British Design Council (Benton et al., 2018) and *The Business Value of Design* by management consulting firm McKinsey (Sheppard et al., 2018), which advocate for design as a driver of growth and innovation. In the McKinsey report, Sheppart et al. (2018) demonstrate that companies with strong design capabilities "increase their revenues and shareholder returns at nearly twice the rate of their industry counterparts". They highlight key areas of action for companies to improve their "design performance", such as breaking down functional silos and integrating designers in cross-functional teams.

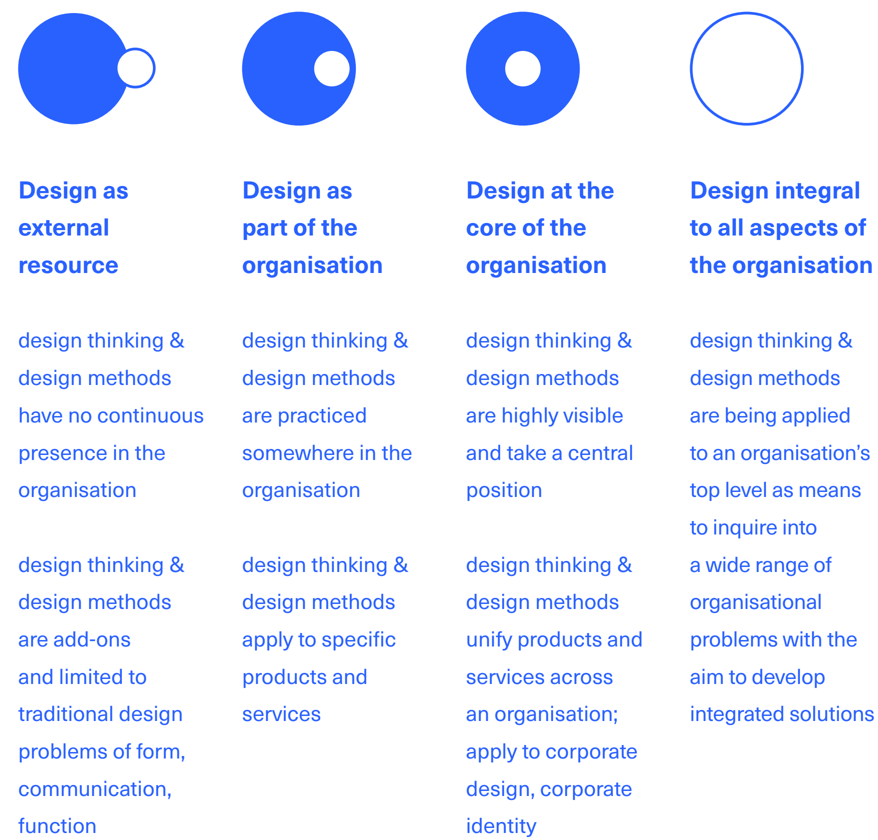
DESIGN AND GOVERNMENT

Following the increased interest in the private sector, there has also been a growing drive to adopt design approaches in the public sector. Government and governmental agencies around the world are trying to address problems utilising design methods on various scales, from policy to services, often inspired by Brown's design thinking concept. For example, the previously cited Design Council is a government advisor on design which aims to inform British public policy. In Denmark, MindLab (which ran from 2002 to 2018) was a pioneering cross-ministerial innovation unit set to transform public service systems with a human-centred approach. Moreover, Finland has been at the forefront in promoting design in the public sector (McNabola et al., 2013), initially with Helsinki Design Lab, initiated and supported by SITRA (Finnish Innovation Fund) in 2009-2013. More recently, notable initiatives are Inland Design, an innovation lab in the Finnish Immigration Service, and D9, a former digitalisation consulting team situated in the State Treasury of Finland.

A growing number of reports and academic research on this topic can be observed (e.g. Kimbell, 2015; Lin, 2014; Malmberg, 2017). Researchers have been widely discussing the benefits, challenges and opportunities of design approaches in the public sector. However, compared to the more established integration observed in the private sector, in this case there are still many barriers that need to be addressed, with little hard evidence to back up the ambitious claims (Mulgan, 2014).

ASSESSING THE INTEGRATION OF DESIGN

One way to understand the extent to which design and design approaches are integrated in public and private organisations is to create models. Notable examples are the Public Sector Design Ladder (McNabola et al., 2013) and the Design Ladder (Ramlau, 2004). Juninger's (2009) model (Figure 6) is here taken into consideration as it provides a way to "place" design within an organisation. It also takes into account the source of design, which could be internal as well as external. Juninger describes four "archetypical" models: external resource, part of the organisation, at the core of the organisation and integral. It is important to note that these models refer to design thinking and design methods, rather than to designers themselves as professional figures. This is one of the models I have adapted and integrated for the purpose of researching design within the academic context.



→ **Fig. 6**
Four archetypical models of design's place within an organisation (Juninger, 2009, Figure 1)

2 - 4 Design in the process of scientific research

Although a large body of research has investigated the role of design in business and more recently in government and policy making, very little is known about the potential role of design in an academic research environment. However, as Peralta and Moultrie (2010) point out, the lack of literature does not imply a lack of cases. Some notable examples are the MIT Media Lab (Cambridge, United States), a laboratory within MIT that employs designers, engineers, artists, and scientists, and the Urban Complexity Lab (Potsdam, Germany), an interdisciplinary research group at the Potsdam University of Applied Sciences working at the intersection of computer science, interface design and the humanities. Many more initiatives are emerging, however access to information about them is limited (Peralta & Moultrie, 2010). In this section, I outline current literature on the role of design and collaboration between designers and scientists in the context of academic research.

A meaningful account is provided by Rust (2004, 2007), who researched design and the natural sciences. He builds on the work of Polanyi (1958), especially on the notions of "illumination" and "tacit knowledge". He agrees with Polanyi in recognising a "creative dimension" of scientific inquiry, who uses the term illumination to describe the process by which a scientist recognises an idea or hypothesis. In their view, such a process of discovery is the result of a rich and deep understanding which cannot be explained explicitly. In other words, it relies on the scientists' tacit knowledge. Moreover, illumination is the leap that bridges the existing with the imaginary, the "reality" with a new world of possibilities. Rust suggests that it is in this context that designers' ability to imagine and test new scenarios can come into play. He argues that systems of representations, which designers can provide, play a very prominent role in the development of thought. Rust then proposes the idea of "investigative designing" and, based on some anecdotal examples of collaboration between designers and scientists, identifies various ways in which designers can contribute to the scientific research process. Peralta and Moultrie (2010) summarise Rust's writings by creating a division between design contributions and benefits to scientific research, as reported in Table 3.

Finally, Rust suggests two possible barriers to collaboration. First is the designer's self-image. The designers might be relegated to minor roles (or no role at all) if they do not believe that their contribution is related to the activity of research and the creation of knowledge. The second problem is how collaborators perceive the designers' contribution, which might not be recognised.

When observing specific disciplines of design in relation to scientific practice, graphic design has been one of the objects of study. Cheng and Rolandi have advocated for the importance of figures in science and for collaboration between designers and scientists (Cheng et al., 2017; Cheng & Rolandi, 2015; Rolandi et al., 2011). They have set up the Design Help Desk at the University of Washington, a free service that offers visual design advice to faculty and students. They have observed a key benefit

Contributions (role of design)	Benefits for scientific research
• Designing artefacts for testing and experimentation • Ideating scenarios • Finding applications for scientific research outcomes • Visualising scientific ideas	• Unlocking tacit knowledge • Connecting scientists with the non-scientists, and helping to disseminate scientific knowledge amongst the general population • Facilitating the advancement of scientific research by providing means of experimentation and reflection • Challenging scientists' perceptions and encouraging the pursuit of new research directions

←
Table 3
Summary of Rust (2004, 2007) (Peralta and Moultrie, 2010)

from the one-on-one consultations offered by the Help Desk: by having to interact and explain to non-experts, the students and researchers would be able to clarify the important aspects of their research (Cheng & Rolandi, 2015). Moreover, in a further article titled "Proving the value of visual design in scientific communication" (Cheng et al., 2017) they compared scientists' perception of Graphical Abstracts (GAs) between original ones from scientific papers and a redesigned version (Figure 8). They were able to demonstrate that "well-designed GAs make papers seem more interesting, more clearly written and more scientifically rigorous" (Cheng et al., 2017, p.80). More recently, Khoury et al. (2019) also argued for promoting "science-graphic art" collaborations. They claim that while these collaborations can certainly improve research figures (e.g. visuals for publication and presentation), they can have the most impact when aiming to reach a broader audience. They cite as a driver the pressure from scientific and funding organisations to improve public outreach and to broaden the impact of the research.

Perhaps the most detailed account is the one provided by Peralta, Driver and Moultrie at the University of Cambridge (UK), who have produced a body of research about collaborations between scientists and product designers (Driver et al., 2011, 2010; Moultrie, 2015; Peralta, 2013; Peralta et al., 2010; Peralta & Moultrie, 2010). They have focused especially on the sub-discipline of Product/Industrial Design and on the process of scientific research oriented to technology transfer and development of applications. A significant part of their contribution is empirical research of case studies, which originated in

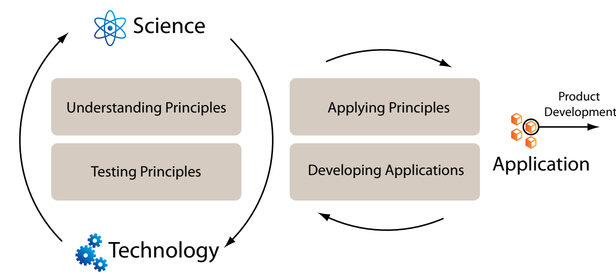


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Fig. 7
Model of scientific research (Driver et al., 2011, Figure 2)

the context of university Technology Transfer Offices (TTOs), entities concerned with commercialisation of research and technology transfer.

In Driver et al. (2010) they have interviewed scientists to investigate their perception of design. There are two notable implications in their findings: (1) scientists' knowledge and perception of design and designers' skills is limited, unless they have had previous experience of collaboration; (2) design intervention could be suitable for many scientists, however the scientists believe that it could have a greater impact in applied research (Driver et al., 2010). In Peralta et al. (2010) and Driver et al. (2011) they have investigated three case studies to uncover the possible contribution of design as well as barriers and facilitating factors to the collaborations. All the cases featured a scientist-designer relationship, which resembled a client-design consultant relationship (Peralta et al., 2010). In Driver et al. (2011) they summarise the findings by comparing design contributions, barriers to collaboration and enablers to collaboration across literature, interviews and case studies.

Moreover, Moultrie (2015) provides an additional anal-

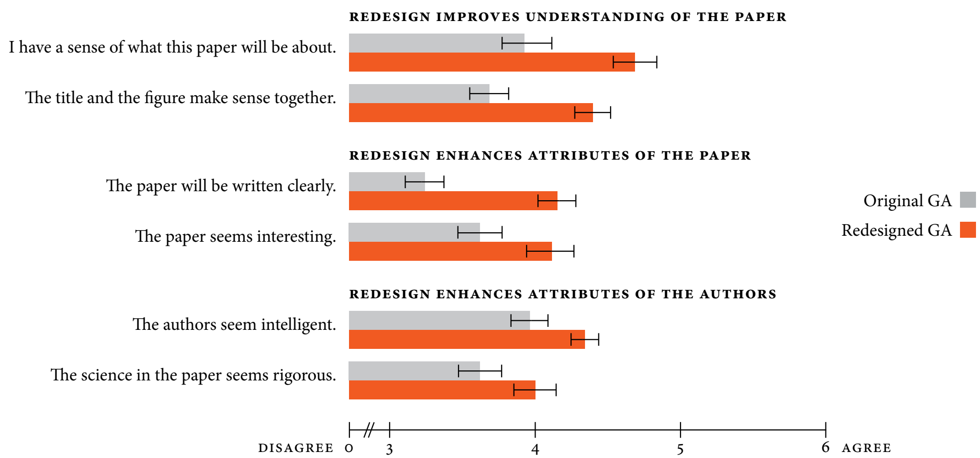

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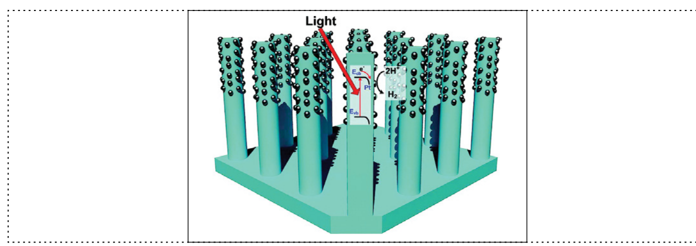
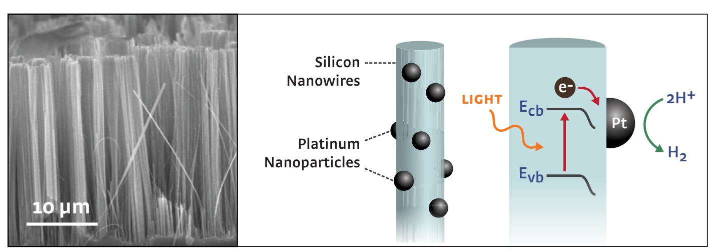
Fig. 8
Comparison between original and redesigned GAs (Cheng et al., 2017, Figure 3)



ORIGINAL
Too cluttered—also, interior diagram too small to be legible.



REDESIGNED
Reformatted using a series of close-up views.

←
Fig. 9
An example of an original and redesigned GA (Cheng et al., 2017, Figure 1)

ysis which focuses on the role of “design demonstrators” in supporting the transfer of technology from the laboratory to the market. He proposes the definition of design demonstrator as “translator objects”, artefacts that can play a complex role in the research and transfer process. Among other reasons why a demonstrator might be produced, he cites the demonstration of scientific principles and technical feasibility of applications, the visualisation of potential future applications and the support to communication within and outside the scientific community.

More recently, Rothkötter et al. (2019) have researched the integration of design in the scientific context. Instead of focusing on the process of collaboration, they describe “design capabilities” and their integration in the academic research environment. They are especially concerned with the design-science-technology intersection and the contribution of design to innovation. Buchanan’s Four Orders of Design (FOD) (1992, 2001) are used to analyse cases identified from the literature, which seem to be often first-of-their-kind and exploratory. The authors argue that such initiatives span all four orders of design and anticipate a trend towards the third and fourth orders, as can be seen in other organisations, moving from an ad-hoc use of design to the “strategic integration of design capabilities supported by design management” (p. 1052).

ASSESSING THE COLLABORATION: MODELS, CONTRIBUTIONS, BARRIERS AND FACILITATING FACTORS

Peralta and Moultrie (2010) argue that designer-scientist collaborations can be framed as interdisciplinary activities, after identifying design and science as separate disciplines. They draw the term interdisciplinarity from the field of interdisciplinary studies, referring to “the integration of concepts, philosophies, and methodologies from different fields of knowledge” (Derry & Schunn, 2005, p. xiii). This notion is comparable to Keskinen’s definition (2010), as explained in [2-1]. Consequently, they deem it useful to draw from literature in interdisciplinarity studies to define types and models of collaboration and to identify problems and elements that enhance them (Peralta & Moultrie, 2010). Adapting elements from Epstein (2005) and Klein (2005), Peralta and Moultrie (2010) propose a model suited for design and science collaboration. Their categorisation is composed of the following four levels of research engagement:

(1) Research in which designers act as “design suppliers” and in which the design tasks are determined by the research group. The design tasks are not directly related to the research questions and designers have no research membership.

(2) Designers are members of the research group, but their tasks are associated specifically to “design” issues agreed upon by the team. Tasks are not directly related to the research questions.

(3) Research in which the designers’ activity is directly related to the research questions but the research agenda is set and led by the scientists. Disciplinary roles are kept.

(4) Research in which designers and scientists team up to define the research questions and to find answers. Disciplinary roles are blurred and activities are defined by research questions.

(Peralta & Moultrie, 2010, p. 1649)

Although this categorisation is supposed to describe different levels of interdisciplinary engagement, it seems that a wider notion of multi-disciplinarities is applicable instead. In the first three levels, designers do not have any role in defining the research problem and different methods are not necessarily integrated. These seem to represent cases of non-egalitarian crossdisciplinarity, as the research process is addressed from the point of view of the scientific discipline. While the designers' perspective and knowledge is included, it is done so occasionally and for specific tasks. Only the last level could be considered interdisciplinary, as the collaborators define the research questions and work on them together.

As previously mentioned, in Driver et al. (2011) they integrate the findings from the literature (Epstein, 2005; Klein, 2005; Rust, 2004, 2007) with findings from their empirical research (Driver et al., 2011, 2010) to propose a range of possible design contributions, barriers and facilitating factors or enablers. The results can be seen in Figure 10. These results as well as the integration model by Juniger outlined in [2-3] are adapted in this thesis for data gathering and analysis.

Table 10. Comparison of design contributions to scientific research.

How can industrial designers contribute to scientific research?	*Literature Review*	*Interviews*	*Case Studies*
Prototyping for quick testing of ideas.	✓		✓
Challenging scientists' perceptions.	✓	✓	✓
Applying scientists' underlying theories.	✓	✓	✓
Creating artefacts to aid understanding and stimulate ideas.	✓		✓
Assisting with communication and dissemination of research.	✓	✓	
Visualising scenarios of use.	✓	✓	
Creating technology demonstrators.		✓	
Producing devices/processes/spaces to enhance scientists' research capability.		✓	✓
Performing user and market research to enhance the commercial potential of the outputs of scientific research.			✓

Table 11. Comparison of barriers to collaboration between designers and scientists.

What barriers may affect collaboration between designers and scientists?	*Literature Review*	*Interviews*	*Case Studies*
Collaborators may not recognise designers' contribution.	✓		
Designers' self image.	✓		
Lack of a shared formal language.	✓	✓	✓
Scientists may be unclear about designers' skills, areas of expertise and role within the team.		✓	✓
Designers may lack the technical/scientific expertise to make a meaningful contribution to scientific research.		✓	
Scientist's willingness to be challenged.			✓
Mismatch between perceived readiness/appropriateness for application.			✓
Intellectual property.			✓

Table 12. Comparison of enablers to collaboration between designers and scientists.

What enablers may affect collaboration between designers and scientists?	*Literature Review*	*Interviews*	*Case Studies*
Designers should be confident in the validity of their research contribution.	✓		
Collaborators should be aware of each others' skills, knowledge and role in the team.	✓		✓
Seek open minded collaborators.	✓		
Collaborators should maintain frequent contact.		✓	
Scientists can perform thorough testing of prototypes.			✓
The creation of artefacts such as visualisations, sketch models and prototypes can aid communication and understanding.			✓
Designers should engage scientists in collaborative work rather than be prescriptive.			✓

← **Fig. 10** Comparison of contributions, barriers and enablers (Driver et al., 2011, Table 10, Table 11, Table 12)

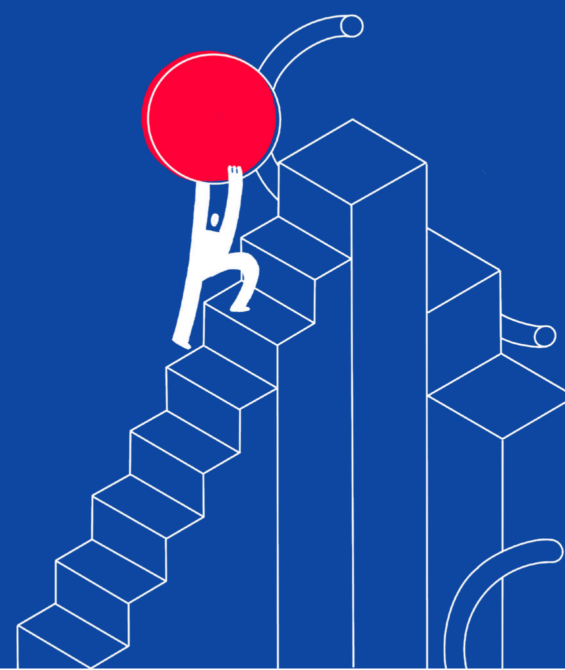
Summary

This literature review has explored the topics of changing paradigms of knowledge production and of the integration of design in organisations and academia. Firstly, new modalities of knowledge production have emerged as relevant in order to address complex contemporary challenges, such as social and environmental sustainability. Multi-disciplinary collaborations, especially interdisciplinary and transdisciplinary, are one of the new paradigm's crucial characteristics. Subsequently, scientific institutions are being pressured to adapt in order to account for such collaborations. Moreover, in light of the changing paradigms, communication and visual representation are established as relevant and valid aspects of knowledge production.

At the same time, design as a discipline is increasingly moving towards abstract domains, and design thinking has become a widely popular account of design. Therefore, design and designers are being incorporated in public and private organisations, more and more in strategic positions. Design integration in academia, despite being a little studied topic, is emerging as well. In this context, design-science partnerships are seen as multi-disciplinary collaborations. Some studies have begun to assess the benefits and limitations of such collaborations, however, more research can be done in order to advance understanding on this issue. Nevertheless, I have identified models regarding the integration of design which I can integrate in my own research, as will be described in the following chapter.

3

Methodology and methods



3 - 1 Case study methodology

RESEARCH APPROACH: QUALITATIVE RESEARCH

A qualitative research approach was chosen for its ability to explore existing or emerging issues in their complexity. Qualitative research is employed in order to uncover little-known aspects of a chosen topic and to formulate research problems or questions. It relies on smaller samples and therefore sacrifices breadth, an advantage of quantitative research, in favour of depth. The data is usually collected through multiple sources and methods, such as interviews, direct observations, or archival records, and is examined by the researcher from various angles (Muratovski, 2016).

Muratovski (2016) summarises the purpose of qualitative research as "the construction of a rich and meaningful picture of a complex and multi-faceted situation" (p.48). The type of knowledge produced through qualitative research can then be described as "concrete, context-dependent knowledge" (Flyvbjerg, 2006) and strives for particularisation instead of generalisation or explanation (Stake, 1995). Stake agrees with von Wright (1971) in noting that although the outcomes might be presented in the form of explanation, the epistemological difference with quantitative research lies in the inquiry's goal, which is learning and promoting in-depth understanding rather than creating explanations. Moreover, Flyvbjerg (2006) argues that "from both an understanding oriented and an action-oriented perspective, it is often more important to clarify the deeper causes behind a given problem and its consequences than to describe the symptoms of the problem and how frequently they occur" (p.229).

The general goal of this master's thesis is to provide a deep understanding of a phenomenon, however, to describe more specifically the function of this research it can be helpful to use the classification proposed by Ritchie (2003) of contextual, explanatory, evaluative and generative qualitative research. This case can be considered one of contextual research since it's concerned with describing what exists and how. Mapping the elements and dimensions of design-science collaborations, and identifying individuals' roles and collaboration modalities, are the goals of this research.

METHODOLOGICAL FRAMEWORK: CASE STUDY

I have chosen the case study as a methodological framework for it can be valuable to uncover the dynamics of a phenomenon, in this instance what happens when designers and scientists collaborate in the context of academic research. This approach provides tools to understand the nature of phenomena given a determined time frame and context, gaining insights from the experiences of individuals in a "real-world" setting (Muratovski, 2016). Among many definitions, Yin (2009, quoted in Yin, 2011) describes the case study as "an empirical inquiry about a contemporary phenomenon (e.g., a "case"), set within its real-world context" (p. 18). Stake (1995), another prominent methodologist, refers to it as a "bounded system" and identifies four characteristics of its research: "holistic", "empirical", "interpretive" and "empathic". These characteristics refer to the importance of the relationship between the case and its context (holistic), the way observations are formed in the study (empirical), the role of the researcher (interpretive) and the approach towards the individuals' experiences (empathic).

A case study can be useful mainly for generating and testing hypotheses but not restricted to these purposes only (Flyvbjerg, 2006). Closely related to the purpose of the research is the criteria through which the case is selected. Flyvbjerg (2006) describes different types of strategies for selection under two main categories: (1) random selection and (2) information-oriented selection. The case in this thesis falls under the second category and can be described as an "extreme case", which Flyvbjerg defines as being "especially problematic or especially good" (Flyvbjerg, 2006, p. 229). Regarding the question of the role of design in science, Aalto University has been chosen as it is strategically positioned. Its newly established physical and academic space make for an especially fertile ground for cross-contamination of design and science, which will be described in chapter [4].

While the design of this study is single-case, it is a nested case as it is composed of several units of analysis

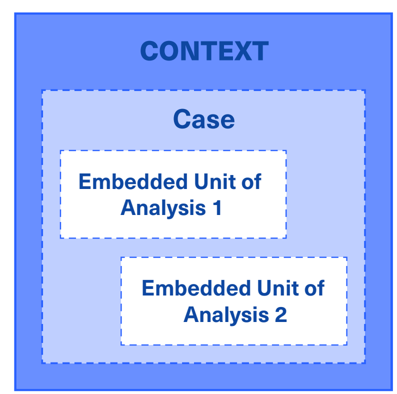


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Fig. 11
Model of case study design (Yin, 2011, Figure 1.1)

(Yin, 2011). There is one context (Aalto University) and one case (design-science collaboration), however, there are multiple instances that have been analysed under this umbrella. These units will also be described in the following chapter.

RESEARCHER'S POSITION

In qualitative research, the researchers achieve understanding through proximity to the reality of the case (Flyvbjerg, 2006). This process of achieving understanding also requires interpretation, which is a fundamental aspect of any research. By immersing themselves in the context, observing and gathering data, researchers draw their conclusions. However, the researcher or interpreter simultaneously records and reflects on the meanings of the recording (Stake, 1995). Stake notes how observations become assertions through a process of interpretation, which requires drawing from personal understandings. These understandings are deep within us and may derive from "some hidden mix of personal experience, scholarship, assertions of other researchers" (Stake, 1995, p. 12).

For this master's thesis, it is important to describe the way I, as a researcher and designer, am close to the context of research as well as the tacit ways in which my personal understandings may have been formed. Since I started my master's studies at Aalto University in 2017, I have been collaborating in various forms with researchers from different departments. I have created data visualisations, concept graphics and illustrations for research groups in electrical and chemical engineering, land use and planning as well as arts. These experiences prompted me to explore this topic and gave me first-hand insights into what it means to be part of a science-design collaboration. It was also through this work that I connected with people working in this field, such as the Materials Platform's designers, whose ARTSList program I was a participant of.

Acknowledging my personal experience related to the topic of study, I have strived during this research to understand the actors' points of view and how they experience this topic. Although my interpretation as a researcher will inevitably be prominent, I have tried to preserve the different perspectives held by the people involved, or what Stake calls "multiple realities".

The on-going interpretative work as a researcher and the explorative nature of the research also kept me open to redirect my perspective on the case as the study progressed and more observations were recorded. I practised what Parlett and Hamilton (1976, cited in Stake, 1995) call "progressive focusing", as I modified initial research questions as new issues became evident. What started as an inquiry into visual design and communication of science became a study of the role of design in scientific knowledge production, shifting the focus from the visual component to the knowledge production process and the interaction between different disciplines. Keeping the case "open" was an important part of the iterative and explorative process.

3 - 2
Data gathering

IN-DEPTH INTERVIEWS

The main source of data for this thesis is sixteen interviews that I have conducted during the months of November and December 2019. This method has been chosen as it provides the opportunity to understand the experiences of individuals in relation to the topic and their unique perspectives in-depth (Ritchie, 2003). Legard et al. (2003) describe various key features of in-depth interviews. Firstly there is a combination of structure and flexibility, which allows the researcher to cover the topic in question and at the same time be responsive to issues that might emerge from the interviewee. Another feature is the interactive nature of the method, given that the way data is generated is a result of the interaction between researcher and interviewee. Thirdly, the ability to achieve depth is a critical aspect. This format allows the interviewer to follow up on statements in order to deepen understanding, uncovering the meaning behind initial answers. A fourth feature is the generative aspect of the interview. During the conversation new thoughts might emerge, either spontaneously or directed by the researcher, creating new knowledge or ideas. Finally, the data should be captured in its natural form, which usually means tape-recorded. To ensure all these features interviews are preferably conducted face-to-face, which especially facilitates flexibility, interaction and thought generation.

In order to gain understanding about emerging col-

Profession	Unit of analysis	DES	SCI	MNG
Designer	Platforms	●		
Designer	Platforms	●		
Designer	Platforms	●		
Designer	Platforms	●		
Designer-in-residence	Design Inside	●		
Designer-in-residence	Design Inside	●		
Designer, contract teacher	Design Inside	●		
Designer, contract teacher	Design Inside	●		
Assistant professor, Dept. of Chemistry and Materials Science	Platforms		●	
Assistant professor, Dept. of Mechanical Engineering	Platforms		●	
Associate professor, Dept. of Applied Physics	Platforms		●	
Researcher, Dept. of Bioproducts and Biosystems	Platforms		●	●
Doctoral candidate, Dept. of Built Environment	Design Inside		●	
Researcher, Dept. of Built Environment	Water Scarcity Atlas		●	
Professor, Dept. of Bioproducts and Biosystems	CHEMARTS		●	
Research manager	Platforms			●

laborations between science and design at Aalto University I have approached individuals who are currently or have been recently part of such collaborations, trying to achieve a balance between designers and scientists. I started by reaching out to personal contacts. Then, I gathered new ones by asking for referrals during the interviews or through online research, as I became aware of new instances of collaboration. Sixteen people took part in the interviews, including eight designers, one research manager and seven researchers across various fields of science and technology, as can be seen in Table 4. Most of the interviews were conducted individually, including two interviews with the same person, and one which was a double interview. This resulted in a total of sixteen interviews, which ranged from thirty minutes to one and a half hours, lasting an average of fifty minutes. All the participants have been working, either full-time or contract-based, for Aalto University during the time of the collaboration and, except for two cases in which the interviews were conducted via Skype, they all took place face-to-face, often in the workplace of the interviewee. Interviews were recorded after consent was given by the participants. The privacy notice and consent form can be found in the appendix.

An interview plan was prepared in advance and was used in all the interviews, following a set of questions in a semi-structured format. The goal was to understand what collaborations were like for the people involved and what was their point of view on them. The questions covered various aspects such as what was the process and the different roles involved, what challenges were encountered along the way and finally what can be considered as a

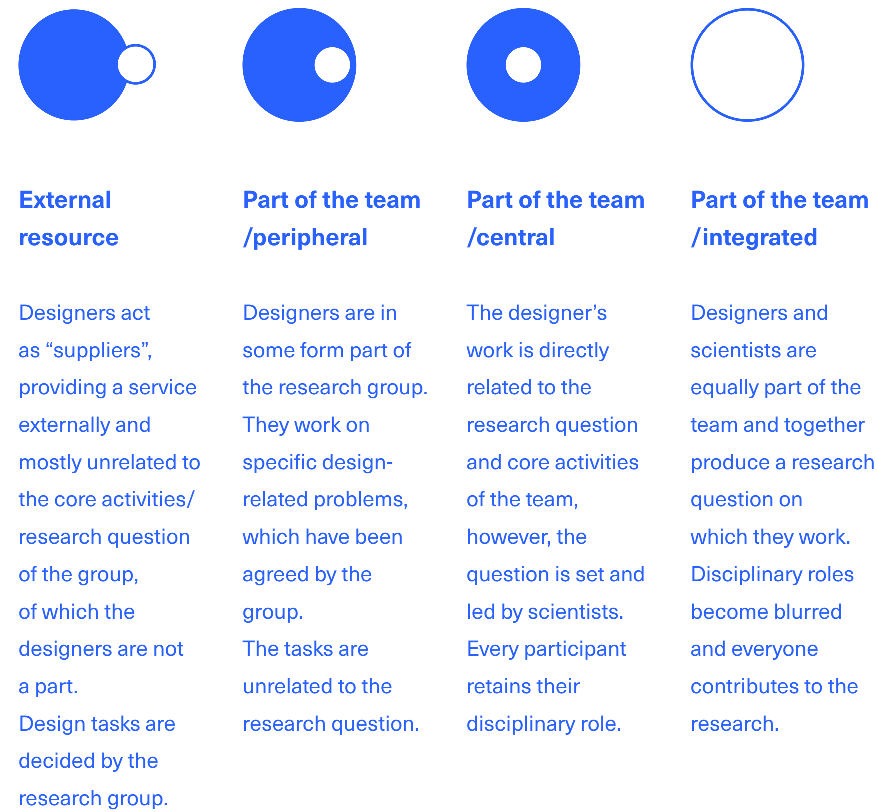
←
Table 4
List of participants, identified by their profession and their relationship to the four units of analysis, described in chapter [4]

DES - Designer
SCI - Scientist
MGN - Manager

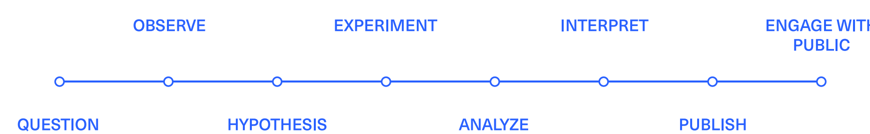
benefit or positive outcome. To achieve both breadth and depth, content mapping and content mining questions were prepared (Legard et al., 2003). The first set was meant to open up the different aspects of the topic, while the second layer was designed to dive into the details under each aspect. The interview plan and questions can be found in the appendix.

Along with the verbal questions, I prepared visual probes to facilitate the discussion and to give tools for the interviewees to reflect on their experience (Mattelmäki, 2006). The goal was to gather detailed information about the nature of the collaborations and at the same time prompt participants' thoughts around the relationship between disciplines and how that relates to the process of scientific knowledge production. The probes consisted of two models based on literature about design in organisations and design-science collaborations. When possible, the visual material was printed and during the interview it was annotated in collaboration with the interviewee. Participants were asked to comment on the probes and if and how they related to them, placing their experience in the models. This exercise often prompted reflections, not only on the present situation but on the possibilities or wishes for the future as well.

The first model (Figure 12) represents a range of engagement of design in a scientific research team. It is based on Juninger's (2009) model of design thinking and design methods in organisations, integrated with Peralta and Moultrie's (2010) four levels of design's engagement in research. Juninger proposed four types: external resource, part of the organisation, at the core of the organisation and integral to the organisation. I borrowed



→ **Fig. 12** Model 1: Engagement of design in a research team



→ **Fig. 13** Model 2: Scientific research process these categories and their visualisation, adjusted them for the academic context and matched them with Peralta and Moultrie's levels, which dealt more specifically with design and science. The latter describe the designer's relation to the core operations of the research group (i.e. research question). The first level depicts designers as external "design suppliers", while the other three refer to designers as being part of the team, with a role increasingly related to the research question (unrelated, related/question set by the scientists, related/question is set together). For the purpose of this thesis, I used these concepts by slightly adjusting and re-writing Peralta and Moultrie's text.

As the proposed model is focused on design and its relationship and integration within a scientific research team, it does not directly address approaches to disciplinary integration. However, similarly to Peralta and Moultrie's model, the first three instances could be considered forms of non-egalitarian crossdisciplinary collaboration (Keskinen, 2010). *Part of the team/integrated* is the only category that would allow for interdisciplinarity.

The second model (Figure 13) represents a simplification of the scientific research process. It is inspired by Müller's proposition for possible applications of design in the scientific method (2018). The goal was to explore how design and scientific work intersect or could intersect from the point of view of the participants and their experiences. Interviewees were asked to identify which phase of scientific research their collaboration took place in. As the two models were placed close to each other, interviewees were also prompted to reflect on the possible relationships between the two.

DOCUMENTS

Existing documents were used as data during this research for two purposes. The first one was to build a picture and a chronology of the context of Aalto University. Especially relevant were strategy documents, the official website, media reports and printed communication material distributed around the campus. The second purpose was to better understand the various collaboration experiences, as documentary review can often be useful in the case the researcher couldn't directly be present and observe certain activities (Stake, 1995). Official reports, media coverage, and official project websites were used to gather data around the collaborations and their outcomes. Moreover, I have collected visual material, produced for and about the projects, to build detailed accounts of the case. When these visual objects were part of the public domain I have gathered them to support written forms of documentation.

3 - 3
Data analysis

THEMATIC ANALYSIS

Thematic analysis is a method oriented to the identification, analysis and reporting of patterns (themes/categories) present in research data (Braun & Clarke, 2006). In this research, I have used thematic analysis to find common themes among the responses from the interviewed participants. For this purpose, the interviews' audio recordings have been transcribed into text and then coded using atlas.ti software following a coding scheme.

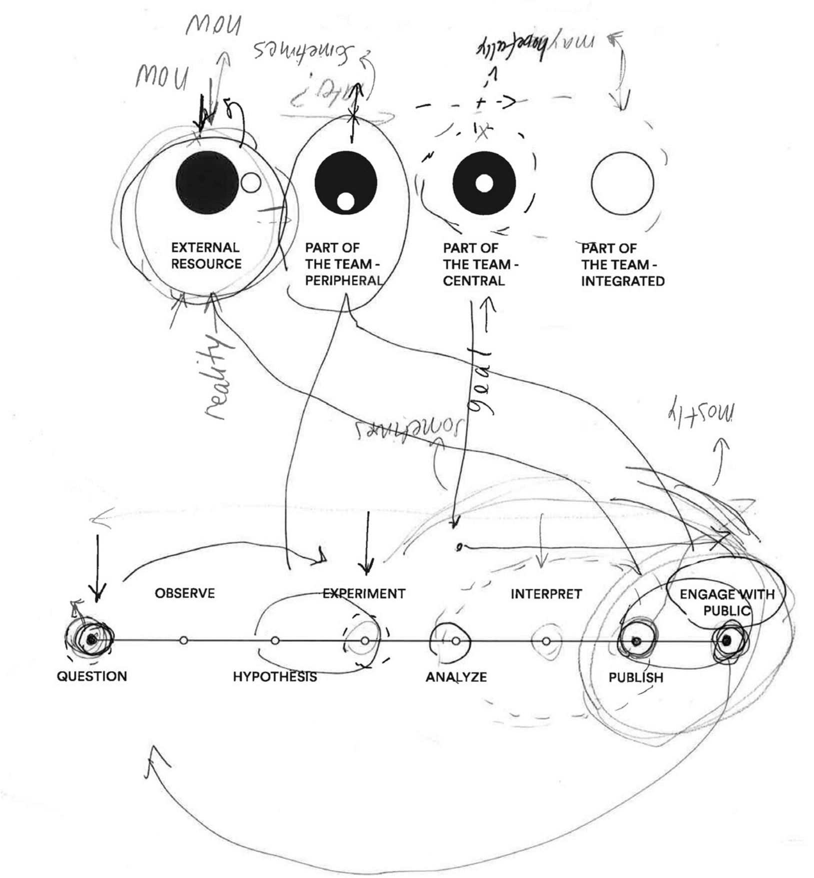
I have developed the coding scheme using a mixed approach of inductive and theoretical analysis. An inductive approach is characterised by being data-driven, as the process of coding does not try to fit the data into pre-existing frames. A theoretical approach instead is based on themes previously identified in the literature (Braun & Clarke, 2006). For this thesis, an initial coding scheme was created based on a deductive approach and then confronted and combined with categories that emerged in the literature review. In the first iteration, I familiarised myself with the data by reviewing transcripts and personal notes. At this phase, I generated an initial set of ideas and started listing and organising what I found interesting about the data. Based on these ideas, I created a first set of codes and then tested them in a series of iterations. Codes were then clustered into themes and assessed in relation to the literature. This step revealed similarities with pre-existing categories, especially the ones found in the work of Rust (2004) and Driver et al. (2011). These helped refine and integrate the coding scheme. Finally, I created a detailed coding scheme (Figure 14) which was applied to the whole set of data. Moreover, I chose the main categories of this scheme to structure the findings chapter of this thesis [5], as well as their discussion in the conclusions [6]. A detailed version can be found in the appendix, with written descriptions for each code.

DATA VISUALISATION AND MAPPING

I have used visual techniques frequently during the analysis process as a way to provide a better understanding and gather insights from the data. Visualising the information wasn't only a means of communicating and presenting the case but it also helped to interpret the data and to generate new knowledge (Verdinelli & Scagnoli, 2013). For example, a combination of documentary sources and interview material was used to create a stakeholder map of the various collaborations that make up the case. The map allowed me to better navigate the complexity of the case by visualising it as a system in which actors are connected to each other within the academic structural framework. A timeline was also created in a similar process to establish a chronology of the case. Stakeholder maps and timelines are familiar tools for designers, often employed in design to represent and communicate concepts as well as processes. They can act as conversation facilitators and thinking material (Giordano et al., 2018). Stakeholder maps especially are used to gain an overview of the relationships in a network, first by identifying the stakeholders, then portraying them visually and finally analysing their relationships (Stick-

→
Fig. 14
Coding scheme

- ▼ **1 Contributions**
  - ▶ 1a Visualising knowledge
  - ▶ 1b Designerly ways of thinking
  - ▶ 1c Design methods
- ▼ **2 Benefits**
  - ▶ 2a Connecting with public
  - ▶ 2b Connecting with academic community
  - ▶ 2c Connecting with stakeholders
  - ▶ 2d Facilitation of research
  - ▶ 2e Challenging perception
- ▼ **3 Barriers**
  - ▶ 3a Time
  - ▶ 3b Budget
  - ▶ 3c Trust & communication
  - ▶ 3d Disciplines' ethos & language
  - ▶ 3e Familiarity & expectations
  - ▶ 3f Structures
- ▼ **4 Facilitating factors**
  - ▶ 4a Positive & open-minded attitude
  - ▶ 4b Time & trust
  - ▶ 4c Mutual benefit & stakes
  - ▶ 4d Institutional support
  - ▶ 4e Physical proximity
- ▶ **5 Activities**
- ▶ **6 Models of collaboration**



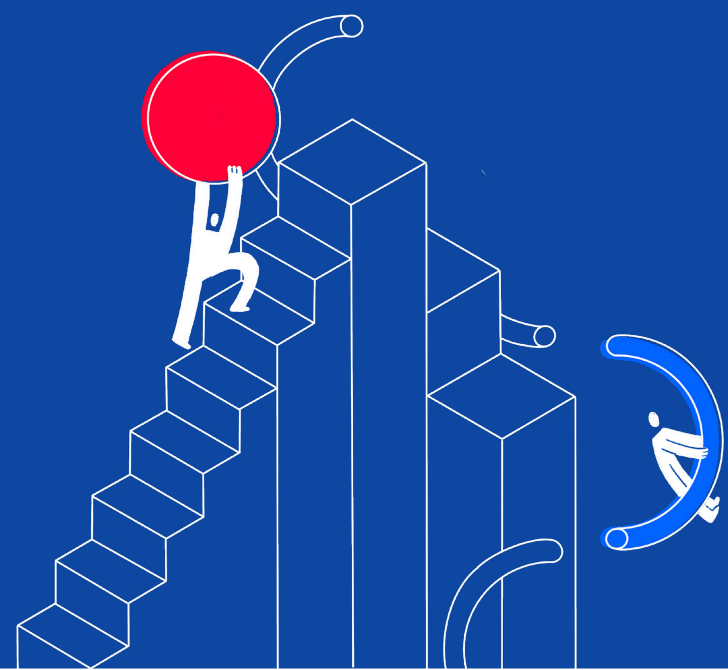
dorn & Schneider, 2012).

The visualisations of the models of collaboration were also instrumental, as they improved the understanding of the models during the interviews, and served as discussion and analysis tools. First of all, they have been used to illustrate the nature of the different collaborations in order to understand and describe the context of the case. Moreover, the annotated models used during the interviews served as an initial step of analysis when, after being scanned and overlaid, they revealed connections and areas of interest (Figure 15). Then a digital visualisation, which can be found in chapter [5], was created to explore the data further and more accurately. In this case as well the visual techniques served both a communicative and analytical purpose.

←
Fig. 15
During the interviews I annotated the models in response to participants' responses, then I overlayed multiple sketches to look for patterns.

4

Case study



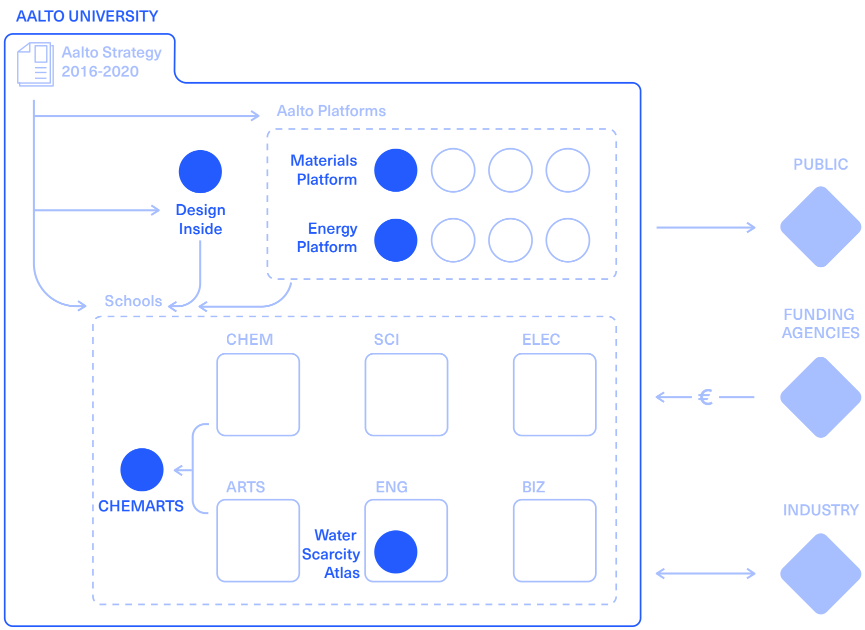


Fig. 16

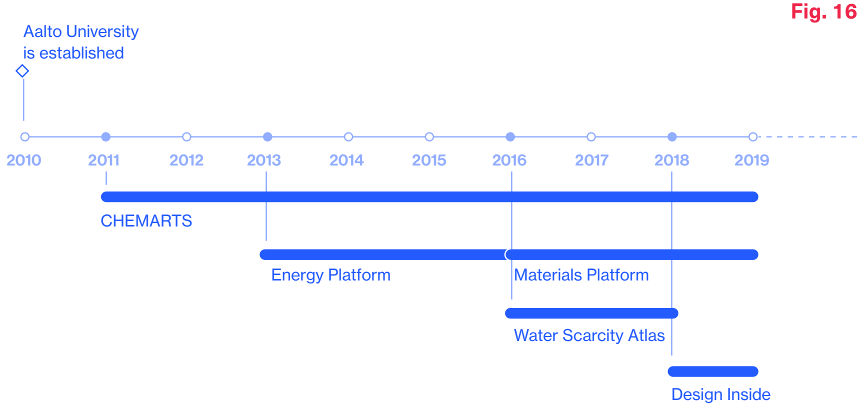


Fig. 17

In this chapter I first introduce the context of the case, Aalto University [4-1], and then I describe the different instances of collaboration, or units of analysis. While the selected units cover many emerging experiences of collaboration, they are not comprehensive of all the instances of collaboration between design and other disciplines in Aalto University. A notable case which I have not investigated is Aalto Design Factory, a product design and learning hub which operates independently, almost as its own "interdisciplinary department". Rather, I have tried to focus on different types of collaborations taking place within the departmental structures of the University. These cases mostly operate in more "traditional" research environments. Moreover, time and access to information limited the research scope as well.

Context: Aalto University

The collaborations studied fall under four units. Firstly, I investigate the activities between the years 2017-2019 of the Energy and Materials Platforms [4-2], two of the Aalto Platforms which employ designers and promote interdisciplinary endeavours within Aalto. Secondly, Design Inside [4-3] is taken into account, an initiative specifically promoting design throughout Aalto. Thirdly, the Water Scarcity Atlas [4-4] was a project of collaboration between engineers in Water and Development and information designers. Finally, CHEMARTS [4-5] is the longest running collaboration I study. It is a joint endeavour of the School of Arts, Architecture and Design and the School of Chemical Engineering. Figure 17 shows the temporal progression of the cases in the context of Aalto University.

Aalto Platforms

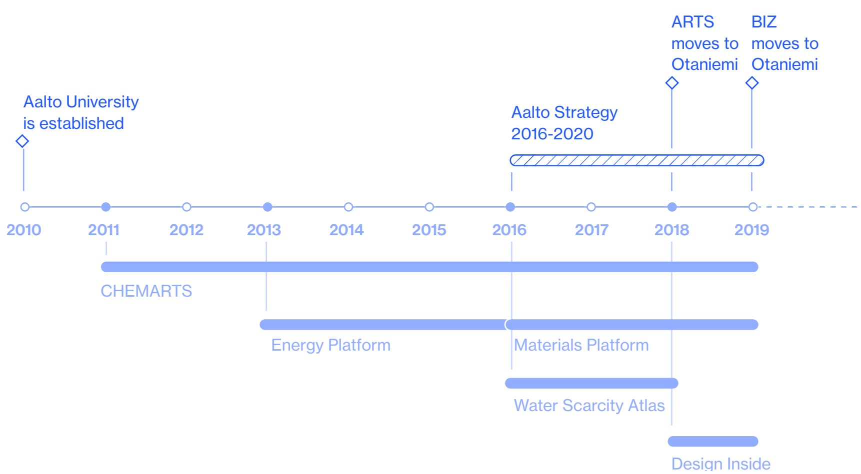
Design Inside

Water Scarcity Atlas

CHEMARTS

←
Fig. 16, Fig. 17
Stakeholder map and timeline of case study

4 - 1
Context: Aalto University



HISTORY AND STRUCTURE

> "Where science and art meet technology and business" (Aalto University, 2012)

Aalto University's history is very recent, although it originates from three universities with a long past. It was established in 2010 as the merger of the Helsinki School of Economics (est. 1911), the Helsinki University of Technology (est. 1849) and the University of Art and Design Helsinki (est. 1871). The idea behind the new university was the coalition of institutions as well as disciplines. The new institution was then structured into six schools: Engineering, Chemical Engineering, Electrical Engineering, Science, Business and Art, Design and Architecture (Aalto University, 2018c).

In 2010, when the university was established, the different schools were based in three main campuses. They were eventually brought together in one location when the school of Arts, Design and Architecture and the school of Business moved from the city of Helsinki to the Otaniemi campus in the city of Espoo, in 2018 and 2019 respectively. The new Väre building is the home for the two schools and it is placed inside an extensive campus that has been the base for the Helsinki University of Technology since the 1950s. Designed by architect Alvar Aalto, whom the university is named after, the vast Otaniemi campus is a Finnish cultural icon and has been historically the home of research in science and technol-

← **Fig. 18** Timeline of case study, with focus on Aalto University

↓
Fig. 19
Campus map

- CHEM/ELEC/ENG/SCI
- ARTS
- BIZ
- *Other*

ogy, hosting many cutting-edge scientific facilities and attracting in its surroundings various industry stakeholders in a rich science and technology hub. Student life has also been part of Otaniemi since the beginning, with the student village for technology students, or Teekkarikylä, being one of the first developments on the site (Aalto University, 2018d, 2018e).

Although Aalto University has created a new identity for itself, the cultural heritage of the different schools is still present. The move to the new campus wasn't met by all with enthusiasm, as leaving behind the physical structures also meant leaving behind part of what constituted the old identities of the schools of Arts and Business. However, the move, as well as many other strategic efforts, created opportunities for culture change and for the encounter of disciplines that before were far apart. Since its foundation, Aalto University has been working towards becoming a "multidisciplinary science and arts community" (Aalto University, 2018e), navigating the difficult tension between the strong culture and heritage of the different universities and the new future-driven identity. Such conditions are what makes it an exceptionally interesting ground to observe the intersection between disciplines. Some participants pointed out during the interviews how change towards a collaborative environment, albeit recent, is ongoing, as seen in these quotes:

> "All this change was done 10 years ago and starting from that historical background, of course there are people who still have that old mindset. [...] We definitely were not pushing for this 15 years ago. And back then it was very much an all boys club. [...] And back then people who would do work like me would be very very marginalised. I had a horrible experience back then and now that I came back it has changed so much, it's way more supporting already"

SCIENTIST / PLATFORMS

> "When Aalto started, I feel that everybody was just, you know, we don't want anything to do with engineers, we don't want to do anything with the designers. But then, little by little, of course also with the younger generations of students [...] have actually pushed us to the direction where we actually do have some collaborations between fields"

DESIGNER / DESIGN INSIDE

STRATEGY

Since the year 2016, the university has been operating under a unified strategy with the mission of "shaping the future" to build a sustainable society (Aalto University, 2015). This strategy will be operative until the end of 2020. The goal is to solve complex societal challenges by combining knowledge from different disciplines, "science and art together with technology and business" (Aalto University, 2015, p. 6). Along with the mission, the encompassing vision is one of an "innovative society", where technological discoveries are integrated with design and business. In the strategy document, Aalto University's research is described as "based on a science and engineering core" (Aalto University, 2015, p. 8) with a special mention of ICT, digitalisation and materials research as areas of excellence. Completing the research profile are art and design and global business dynamics. Furthermore, three main themes can be identified across disciplines: advanced energy solutions, human-centred living environments, and health and wellbeing. The strategy then goes on to outline four strategic objectives with related development actions. The objectives are:

(1) Research excellence for academic and societal impact
(2) Renewing society by art, creativity and design
(3) Educating game changers
(4) Transforming our campus into a unique collaboration hub

Throughout the whole strategy, it can be observed that multidisciplinarity is an overarching theme, seen as a "competitive edge", an important educational tool and a key aspect of innovation for society's benefit. From the transformation of the physical space to the educational offering, all areas of development include an element of promoting collaboration. Examples are two of the actions for objective (1): to advance multidisciplinary endeavours and to establish research environments with opportunities for collaboration. Objective (2) as well is concerned with developing and promoting "art-based activities across the boundaries of diverse disciplines". However, the word "multidisciplinarity", as discussed in chapter [2-1], can mean various forms of collaboration, or no collaboration at all. According to Keskinen's definition

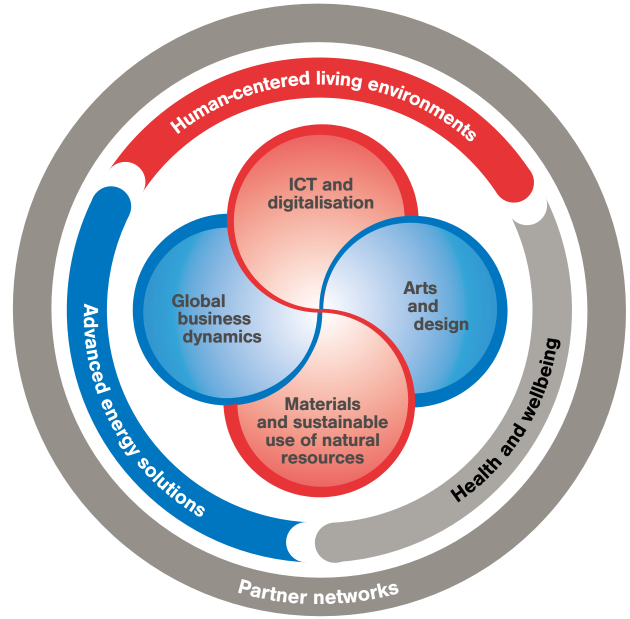


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Fig. 20
Concept graphic of Aalto's reserach profile from the Aalto Strategy 2016-2020 document (Aalto University, 2015, p.9)

(2010), multidisciplinarity doesn't entail interactions between disciplines, but different disciplines looking at the same issue from their own points of view. The central role of the term in the strategy seems to signal the need and the willingness to increase collaboration; at the same time, the lack of specificity could indicate that further work needs to be done in order to define exactly what Aalto is aiming for.

A concrete example of the effort to promote collaboration between departments and disciplines is the Aalto Platforms, which have been gradually established since 2013 (Aalto University, 2018f). In this case, the collaboration is described as transdisciplinary and is organised around areas of research, such as energy, materials or sustainability. The platforms involve different academic disciplines and industry actors. In order to "facilitate transdisciplinary actions" they offer networking and training opportunities, establish collaborations and support them with seed funding, and finally help promote the research through visualisation and communication support.

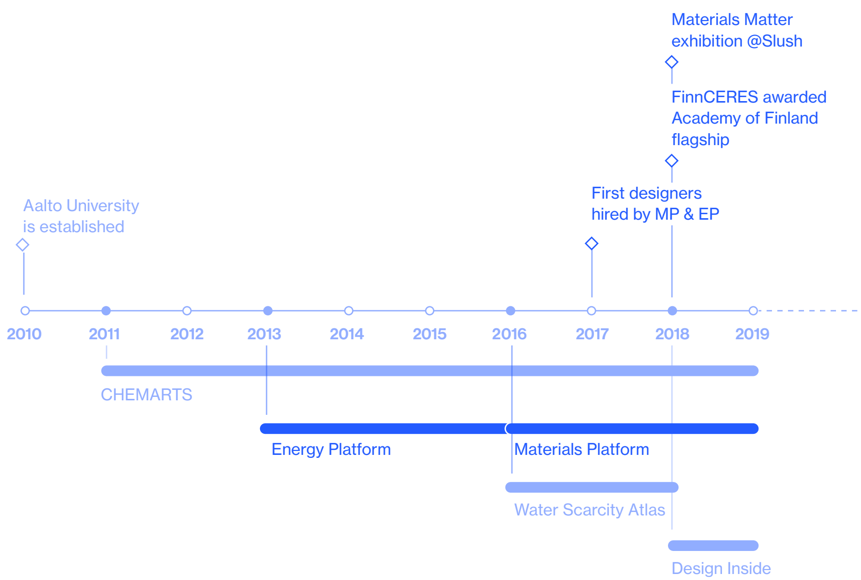
The current strategy will be valid until the end of 2020, when the new one will be adopted. "Strategy 2021 and beyond: Shaping a sustainable future" doesn't employ the term "multidisciplinarity" as often as the previous one, but lists collaboration as one of the three core values (Aalto University, 2019b). It is called a "living strategy" and it states that it was created together with the Aalto community and stakeholders. Parts of the discussion for the strategy preparation are accessible to the Aalto community through an online strategy portal (Aalto University, 2018g). In these discussions there are various mentions of the platforms as a positive example of collaboration, as well as comments challenging the use of the term "multidisciplinarity".

→

Table 5
Statistics about Aalto Platforms for the year 2018 (Aalto University, 2018f)

Platform name	Est.	Aalto professors in the field	Events	Events particip-ants
Digi	2014	160	9	1400
Energy	2013	65	8	450
Entrepreneurship	2017	40	5	400
Experience	2017	50	11	1200
Health	2016	91	7	1900
Living	2015	137	13	450
Materials	2016	85	9	650
Sustainability HUB	2018	97	12	1200

4 - 2
Energy and Materials Platforms



The Energy and Materials Platforms are two of the eight Aalto platforms that were established to promote collaboration between disciplines. The various initiatives organised by these platforms, whose stories are intertwined, have constituted a great part of my research as they were far-reaching and involved many researchers across schools in Aalto. Nine out of sixteen interviewees were involved in activities initiated through the Platforms. Among them, six are people who are, or have been, part of the Platform staff, including two managers, while the other three are science and engineering researchers who have collaborated with them.

CONTEXT

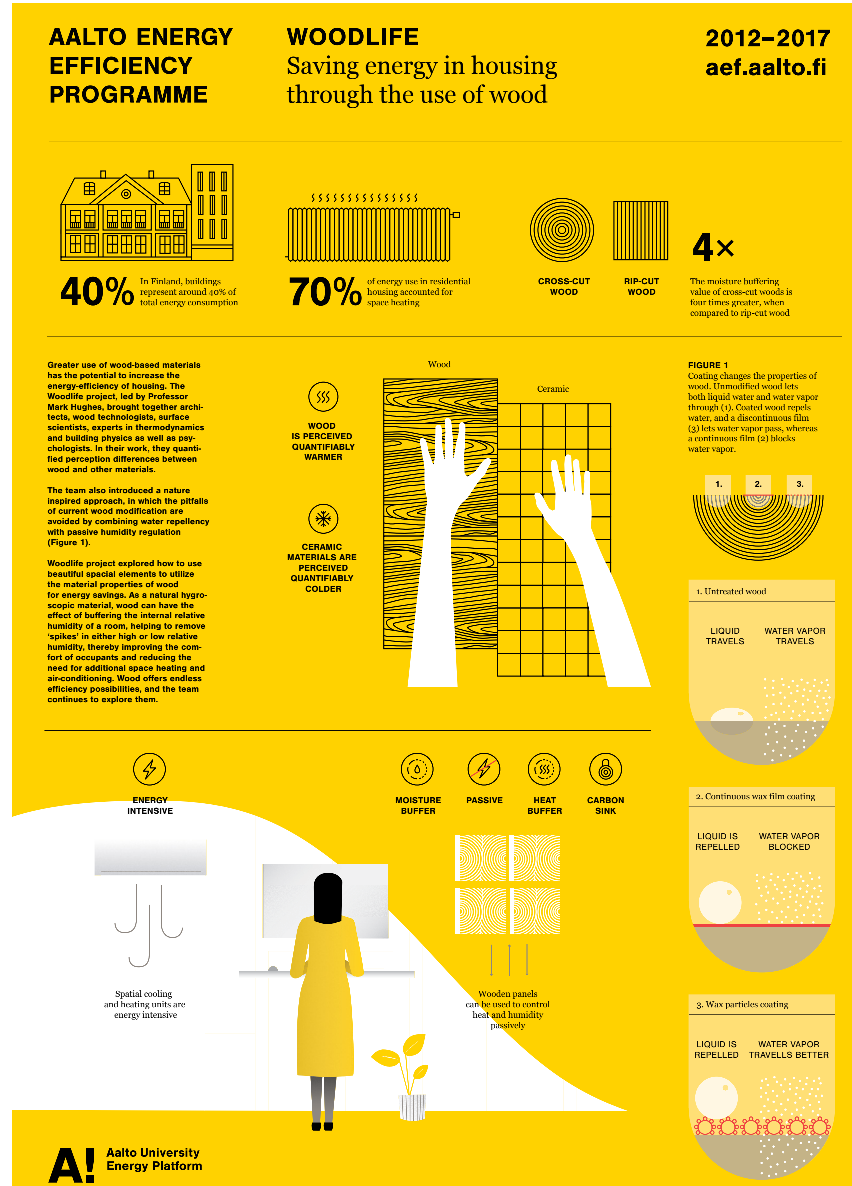
In 2017 the Energy and Materials Platforms came under the management of engineer Kati Miettunen, who at the time was also working as a part-time researcher. For this reason, she was able to hire additional staff to support her work and, inspired by the CHEMARTS experience, she thought it would be beneficial to the platform to include people with skills complementary to her own. Pirjo Kääriäinen, professor of practice in the Department of Design and co-founder of CHEMARTS, supported her in the hiring process and from that first call two design master students became part of the team. What was a summer project became an established way of working, with designers part of the team since then. In September 2018 Heidi Henrickson took up the role of manager for

← **Fig. 21** Timeline of case study, with focus on Energy and Materials Platforms the Materials Platform as Kati Miettunen went back to her full-time research work, while Sam Cross became the manager for the Energy Platform, splitting the team in two. At the time of writing this thesis, the two teams still employ designers, one of them being part of both teams.

ACTIVITIES

Since the beginning, the Platforms were given freedom to experiment with different ways to promote collaboration practices and the range of activities has varied over time. In the case of the Material and Energy Platforms, one of the aspects that was tackled was, for example, the visual communication of scientific research. The team has approached the issue in multiple ways: from providing the researchers with tools by offering training, to connecting research groups with external collaborators, to initiating projects and organising events. Currently, the Materials Platform promotes multi- and cross-disciplinarity by offering the following services: support for events, photography and photography consulting, and visual practices for funding applications. Moreover, they sometimes initiate and take part in interdisciplinary projects (Aalto University, 2018b). The Energy Platform isn't specific in its description, mentioning in their webpage that "the platform organises and gathers energy-related research and activities" (Aalto University, 2018a).

Among the activities that involve the Platforms staff directly was the design of visualisations for grant applications or scientific journals. On one hand, there have been many collaborations with a limited scope and timeframe. For example, an initial approach was to send out a



→ **Fig. 22** Summary poster of Aalto Energy Efficiency Programme, created by a Materials Platform designer (Aalto Energy Platform, 2017) call for papers: researchers looking for help in visualising their findings would provide information about the paper and then the designers would work with them to create scientific figures. On the other hand, they also took part in longer collaborations, such as the work on the funding application for the FinnCERES centre for materials bio-economy, which eventually won the Academy of Finland flagship program (FinnCERES, 2020). Designers contributed to the grant application process by visualising key concepts, helping to prepare the final documentation and eventually the in-person presentation.

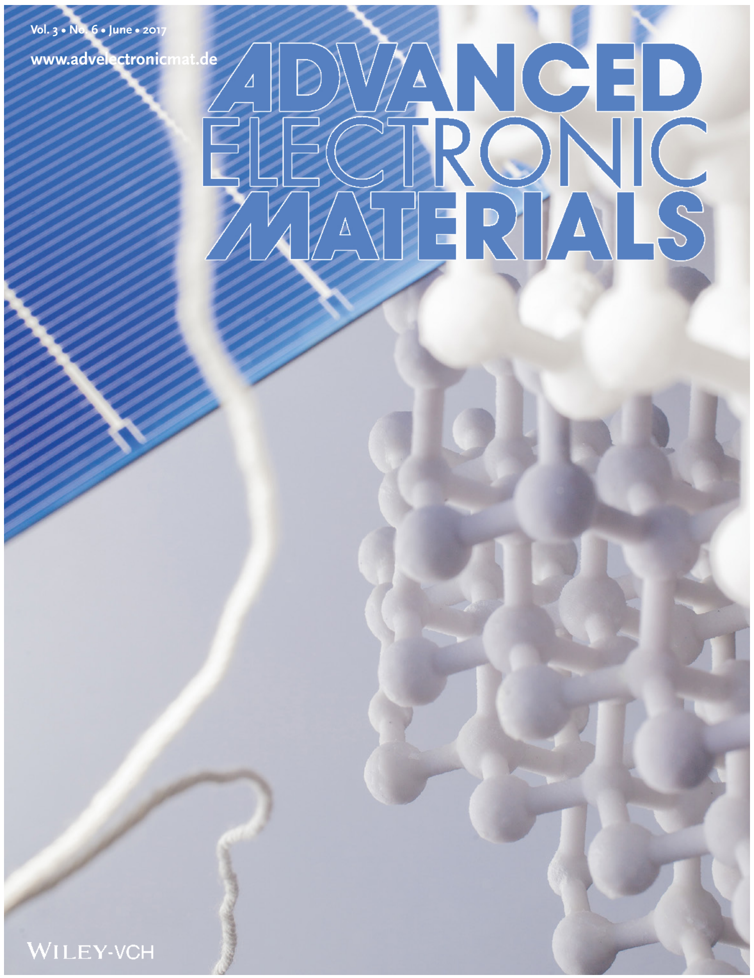
There were many cases in which the Platforms designers couldn't intervene directly in the design work, because of a lack of resources or because it wasn't directly related to the agenda of the Platforms. Therefore, they have been piloting projects to provide support in different ways, such as organising photography and visual communication training sessions. An example of a more experimental initiative is ARTSList, a program to connect design students (myself included) with researchers in need of visualisation work. Very recently the Materials Platform also launched a drop-in help desk (Aalto Materials Platform, 2020). It consists of consulting sessions in which they offer free advice on the visual communication of research to Aalto students, faculty and staff.

Another way for the Platforms to promote collaboration and to communicate scientific research is the organisation of events. A successful example is the Materials Matter exhibition. It was organised by the Materials Platform and originally shown at Slush 2018, showcasing ten materials research projects. Thanks to a positive reception, it was also showcased at Dipoli Hall (January-March 2019) and notably in the summer of 2019 at Finlandia Hall during the Finnish European Union Presidency (Aalto Materials Platform, 2019; Aalto University, 2018i). Two designers were hired specifically for the task, and worked in collaboration with the materials researchers. The goal was to present scientific research findings in an engaging way to a broader audience, by using storytelling, visual communication and exhibition design. The exhibit featured many material samples that were produced especially for the occasion.

↑
Fig. 23
Materials Matter exhibition at Slush (Relander, 2018)

WORKING PROCESS

Designers are a central part of the Platform teams and in the Platform-initiated projects they usually have a prominent role. They are involved first-hand in all activities of the Platforms, from strategic to practical tasks.



However, often they are offering a service to others and act as external design providers. In the latter cases, they follow what can be considered a fairly standard design process. After being contacted by the researchers, they schedule a meeting in which they discuss and re-evaluate the brief, trying to identify the needs of the client. The designers also take time to understand the scientific aspects of the projects and, on this occasion, they might sketch together to figure out an initial idea. After that, they mostly work apart, while staying in contact and ideally having regular face-to-face meetings to iterate on the progress. Final ideas are agreed upon together. There can also be instances in which the Platform team determines that they cannot dedicate resources to a particular project, in which case they might still support it by helping to define the brief and to hire an external collaborator (e.g. designer, photographer).

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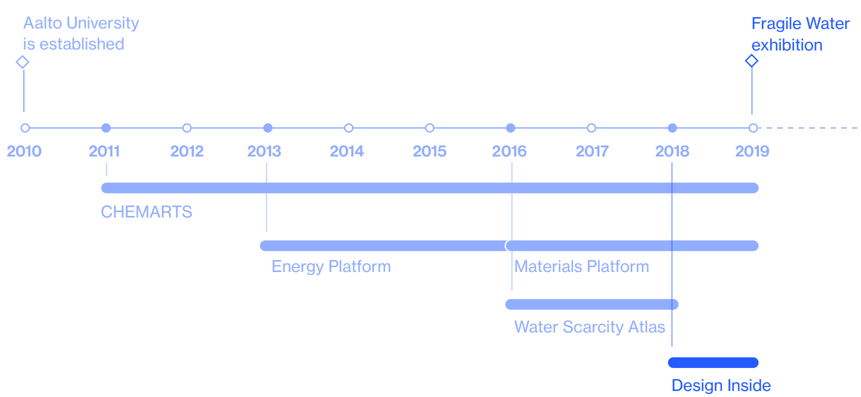
Fig. 24
Journal cover created through a scientist-designer collaboration (Suorlahti & Rinke, 2017)

4-3
Design Inside



Design Inside is an initiative started in 2018 as part of Aalto's effort to promote creativity across disciplines (Aalto University, 2018h). As it is tied to the current strategy, Design Inside in its current form will end at the same time as the strategy, at the end of 2020. The initiative stemmed from the university-wide working group for Art and Creative Practices, the same actor behind University-Wide Art Studies (UWAS), arts-based course offerings for students in all disciplines. Two designers-in-residence are the Design Inside team tasked with the goal of creating mechanisms to spread and integrate design and creative practices across all schools in Aalto. Similarly to the Aalto Platforms, the team was given a lot of freedom to work towards this goal and to find ways to translate the broad strategy into practical actions. They had to identify what would be the content, whom to involve and in what kind of collaborations. The main areas of focus have since been business and partner networks and design education.

According to one of the designers, a strategy for establishing collaborations is to contact professors in Aalto that might be interested or already familiar with a design approach and work together to help them integrate more design content in their courses. Mandatory bachelor courses are preferred for the wider reach they have. An example of a recent experimental collaboration is the introduction of a visualisation assignment during an introductory course for bachelor chemistry students. An information design teacher collaborated with the

← **Fig. 25**
Timeline of case study, with focus on Design Inside

chemistry professor in charge of the course in order to organise a scientific poster design exercise.

FRAGILE WATER EXHIBITION

One of the objects of my research was an initiative supervised by Design Inside called Fragile Water, an exhibition about the vulnerability of global water resources showcased in Helsinki Airport from January 2019 until December 2019 (Aalto University, 2019a). It was the result of the Glass Challenge course, which is part of the Contemporary Design master program in the Department of Design. Enni Äijälä, Design Inside designer-in-residence, had contacted the teacher of the course and proposed a collaboration with the Water and Development research group from the School of Engineering (Department of Built Environment). Research on water then became the topic of the course for that year and teachers, students, researchers and external collaborators worked together to produce the final exhibition.

The collaboration started with a joint workshop, in which researchers introduced themselves to the students and presented five research topics. The seventeen students chose one of the topics based on their personal interest and had a chance to discuss in more detail with the researcher who was the expert in that specific topic. The students gathered ideas and inspiration to then proceed independently with their own artistic process. The teachers of the course promoted the students' freedom of expression and encouraged them to engage with the topics from their own perspective. During the course, there were a few further face-to-face sessions and students occasionally reached out to the researchers to gather more information. At the same time, when the students were working on their pieces, an exhibition designer and a graphic designer supported the process. Researchers collaborated closely with the graphic designer to produce posters that would accompany the pieces designed by the students. The goal was to visualise data related to the five topics, as well as create a story to introduce the pieces to the audience.

↓
Fig. 26
Fragile Water exhibition at baggage claim hall 2B in Helsinki Airport (Passi, 2019)

←
Fig. 27
Fragile Water exhibition piece by Hanna Kutvonen: “It’s not fair” (Kutvonen, 2019)

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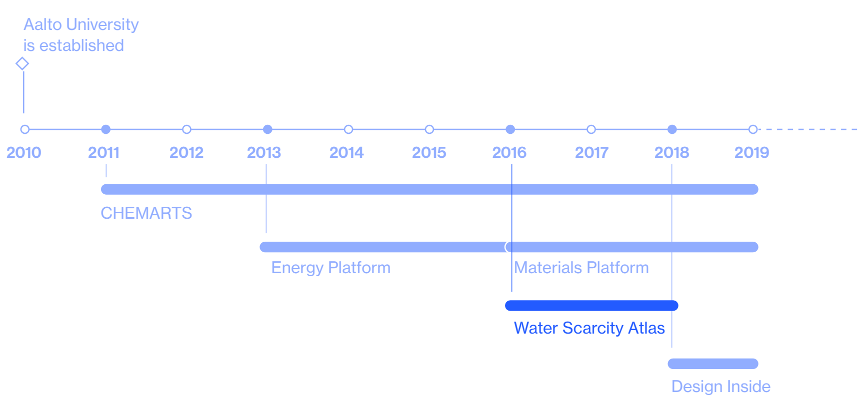
Fig. 28
Students and researchers at the kick-off workshop of the Glass Challenge course (Kinnunen, 2019)

4 - 4

Water Scarcity Atlas



The Water Scarcity Atlas (Water Scarcity Atlas, n.d.) is a website which aims to disseminate scientific knowledge about water scarcity to a broader audience in the public and private sectors. The project was funded through an Academy of Finland grant and it was developed over the course of two years (10.2016-09.2018) by researchers from the Water and Development research group together with design studio Lucify and digital agency Mediapool. While Mediapool had a more straightforward relationship with the research team and worked specifically on the website development, the designers from Lucify collaborated from the early stages in the design of the whole project and were more involved in the decision-making process. Their task was to create two interactive visualisations, which constitute the main element of the website. The project was developed in two phases, first a simplified pilot and then the final implementation.

One of the goals of the Water Scarcity Atlas was to present research data about water scarcity in an accessible way. Such research is based on models and great effort went into showing their impact on the final analysis and the role of uncertainty. There are two central visualisations on the website which exemplify this: the exploration tool and the futures tool. The water scarcity exploration tool lets the user explore past and current data about water stress, water shortage and water scarcity. It allows them to adjust various parameters which the map is based on, such as the choice of water model, climate data or timescale. Through this interaction, the

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Fig. 29
Timeline of case study, with focus on Water Scarcity Atlas

user can see how their choices change the outcome on the world map. Similarly, the futures tool uses interactive methods to show the impact of choices. This case, however, is centred on future scenarios and what would be the consequences of certain actions on water stress or food supply, for example how a drastic change in diet would impact global water stress. Uncertainties are still taken into account by giving the possibility to switch between different water and climate models.

Global static maps are a central part of the research work in the Water and Development group. The researchers are skilled in producing maps for scientific journals as almost every article they publish features some kind of map or visualisation, which is the centrepiece of the paper and conveys the main findings. The researcher I have interviewed mentioned that they can tell when a paper is coming together when the figures are also effectively capturing the message, claiming that in many cases the design of the visualisation is the analysis itself. Given the familiarity that the group already had with the visual medium, they considered that interactive visualisations could be a good fit for reaching a broader audience. When the opportunity came to fund a dissemination project thanks to the Academy of Finland grant, they decided to reach out to a studio which specialised in information design. The novel visualisations featured in the Atlas built upon the static maps that the researchers produced, through a close dialogue between the cartography skills of the group and the design skills of the studio.

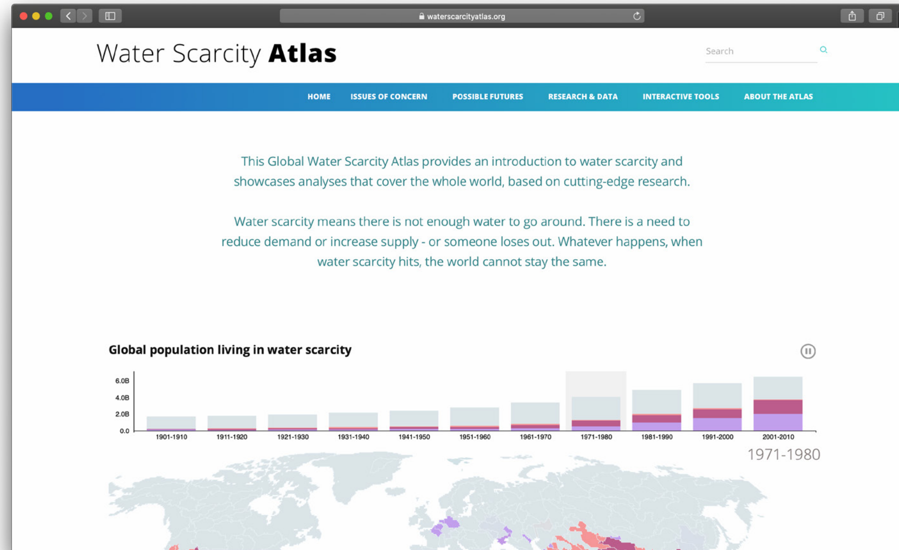

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Fig. 30
Homepage of the Water Scarcity Atlas website (Water Scarcity Atlas, n.d.)

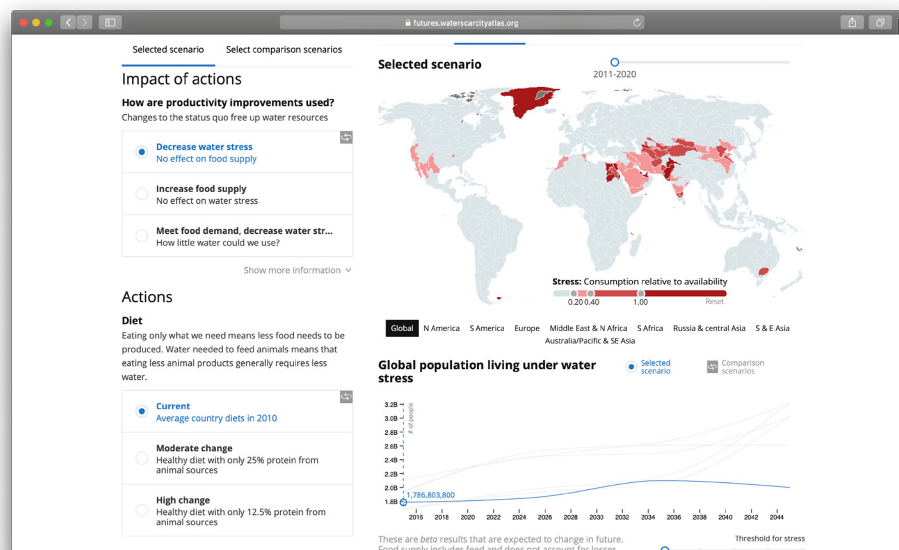

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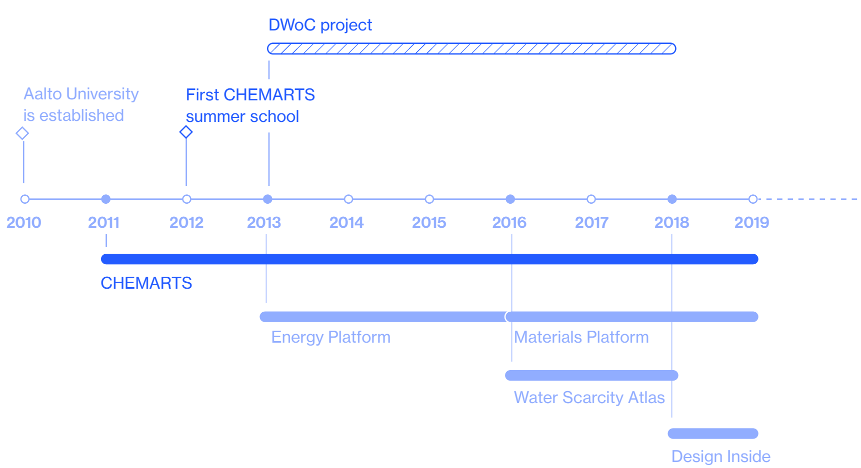
Fig. 31
Interactive futures tool (Water Scarcity Atlas, n.d.)

4-5
CHEMARTS



CHEMARTS is an umbrella term for various research and teaching collaborations between the School of Chemical Engineering (CHEM) and the School of Arts (ARTS). Among the instances that I have researched for this thesis, it is the longest-running, with the first activities starting in 2011 (CHEMARTS, 2020). Initially, new ways to integrate materials research and design were investigated through the project work of students. Then in 2012 an interdisciplinary summer school was established and has been running every year since. CHEMARTS teaching endeavours have kept growing, with new courses such as Design Meets Biomaterials and Plant Biomass added to the curriculum as well as occasional workshops. The summer school and the two courses constitute the CHEMARTS minor program, open to students from all the Aalto schools. Pirjo Kääriäinen, professor of practice in the Department of Design, and Tapani Vuorinen, professor in the Department of Bioproducts and Biosystems, are responsible for the program. They sit close together in the offices of the Aalto Bioproduct Centre and co-teach most CHEMARTS courses. Over time they have been able to get additional support and hired another lecturer and teaching assistants.

← **Fig. 32** Timeline of case study, with focus on CHEMARTS

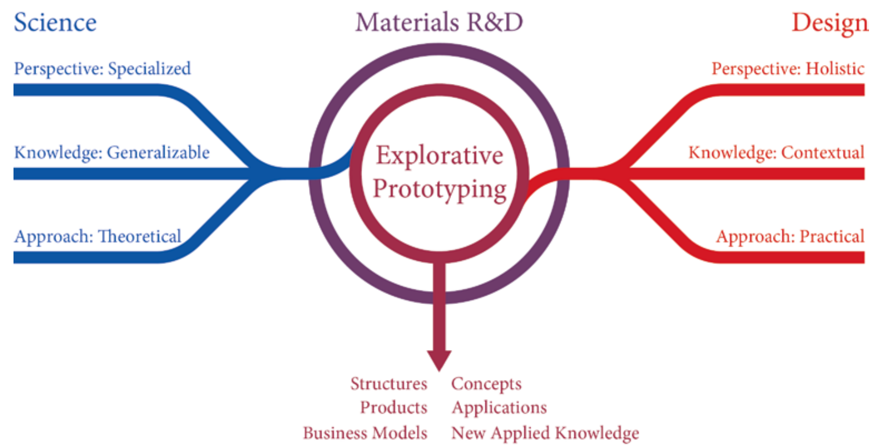
The teaching experiences were the inspiration for the initiation of academic research. Several professors from both ARTS and CHEM are involved in various projects, which are usually funded externally by entities such as the Academy of Finland or the European Union. An example is “Design Driven Value Chains in the World

→ **Fig. 33** Conceptual diagram for DWoC project (Design Driven Value Chains in the World of Cellulose DWoC 2013-2015, 2015, p.7)

→ **Fig. 34** One of the results of DWoC: Cast wood, designed by Heidi Turunen (Kataja & Kääriäinen, 2018, p.75)

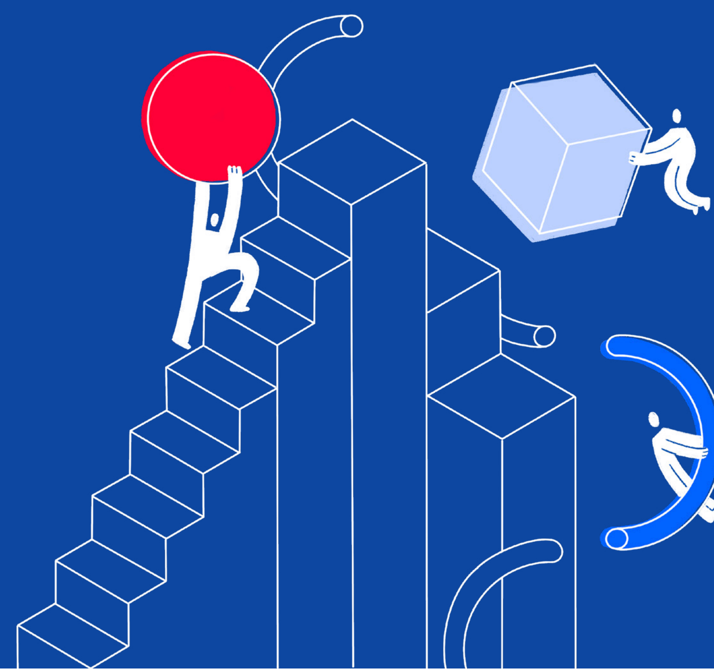
of Cellulose" or DWoC, which took place from 2013 until 2018 (Design Driven Value Chains in the World of Cellulose DWoC 2013-2015, 2015; Kataja & Kääriäinen, 2018). It involved many partners (VTT Technical Research Centre of Finland, Aalto University, Tampere University of Technology and University of Vaasa) and it was funded by Tekes, a large Finnish public funding agency for research. The concept of the project was to integrate design thinking, prototyping and technology competences in order to advance the Finnish cellulose ecosystem. During this project design and technology researchers collaborated in envisioning roadmaps for the future and in creating product concepts and product-service systems. New technologies and materials were tested and prototyped, producing research results which were visually documented and exhibited to different audiences.

The teaching and research work done under CHEMARTS is considered a positive example of collaboration and interdisciplinarity in Aalto. During the interviews that I've conducted, it was often cited as a reference for what a successful collaboration can look like and, in the case of the Materials Platform, it even inspired their own collaboration with designers. The success has also been recognised on a wider university level. In 2014, professors Tapani Vuorinen and Pirjo Kääriäinen were awarded the Aalto Act of the Year Award for their achievements with CHEMARTS.



5

Findings



In this chapter I present the findings of this thesis in order to address the research question: how does design contribute to research processes in the current framework of scientific practice? In order to answer this question, I investigate a series of collaborations between designers and scientists in the context of Aalto University, introduced in the previous chapter. Through a thematic analysis of the data gathered in sixteen in-depth interviews, six themes are identified and assessed in relation to the literature discussed in chapter [2]. These themes constitute the structure of this chapter: [5-1] the contributions of design to the collaboration; [5-2] the benefits of integrating design in a scientific research process; [5-3] the barriers to the collaboration; [5-4]] the elements acting as facilitating factors and finally [5-5] the different models of collaboration.

Throughout, I support my writing with direct quotes from the interviews, in order to voice the participants' perspective directly. The quotes are marked to identify the affiliation of the interviewee with a specific collaboration and their role (researcher, manager or designer).

MNG	Manager
SCI	Scientist
DES	Designer
PLATFORMS	Energy and Materials Platforms
DES-INSIDE	Design Inside
WS-ATLAS	Water Scarcity Atlas
CHEMARTS	CHEMARTS

5 - 1
Contributions

In this subchapter I describe the ways in which design contributes to scientific research processes, as it emerged from the interviews. I summarise the contributions in three main categories: visualisation of knowledge, designerly ways of thinking and design methods. The first one, visualisation of knowledge, refers to the production of visual artefacts. In this research, it was one of the most recognised and common contributions, one which was observed in other studies as well (Cheng et al., 2017; Driver et al., 2011; Rust, 2004). Secondly, I identify designerly ways of thinking as another contribution, referencing Cross's account on design thinking, or the notion of designerly ways of knowing (1982). In this case, the designers' thinking process is singled out as a valuable input to scientific research, complementary and not excluding the scientists' approach to knowledge production. Finally, design methods are considered. Here I discuss the possibility of integrating established and structured methods in the scientific research process.

Visualisation of knowledge

Designerly ways of thinking

Design methods

VISUALISATION OF KNOWLEDGE

One of the most common design contributions identified by the interviewees was the production of knowledge in visual form. As explained in the previous chapter, many of the collaborations engaged designers specifically for this purpose. The visual artefacts varied from illustrations, diagrams and concept graphics, data visualisations, or even physical objects. However, I observed a variation in the perception of this contribution, sometimes regarded as the main contribution or, in other instances, as one aspect of broader work by designers.

The tangible outputs of these collaborations were usually in the forms of digital and printed visual artefacts, except for the case of exhibitions in which it was a mix of printed and three-dimensional objects. Some examples of the most typical outputs are figures for scientific papers and funding applications, posters and brochures, digital slide sets and finally exhibition pieces and graphics. Usually, these visual artefacts would represent either specific research findings, questions and problems or more extensive research summaries and plans.

In the context of this case, the designers' work often seemed to be viewed by scientists as functional, as a "communicational tool". They related the value of the work to its ability to convey meaningful information and contributing to the quality of communication. However, either explicitly or implicitly, the aesthetic component played a role in how the work was perceived and described.

DES / PLATFORMS

"They were super happy in the way we presented it, that we really translated it without shortcuts. They didn't feel that we simplified it too much and they were surprised by how beautiful everything was."

MNG-SCI / PLATFORMS

"It's of course nice to have eye-candy pretty things, but beyond that it's more important to have efficient visual communication. [...] That was something that the designers were able to deliver."

"[They] did also slides for different professors, and the comments were 'I've never had such good-looking slides, these are the best ever'."

DESIGNERLY WAYS OF THINKING

Although in many cases the visualisation of knowledge was the main activity, during interviews with scientists and managers, the designer's contribution was specifically related to the thinking process. This aspect was often mentioned in the context of writing grant applications (in the case of Platform-supported collaborations), and with the planning and development of projects (in the case of CHEMARTS). Although the material and visual artefacts were indeed a part of these collaborations, the interviewees recognised specifically how the designers affected the process of planning and developing ideas.

MNG / PLATFORMS

"I think that the designers are more a part of the whole process of developing the idea that goes into the grant. Even though it probably started off as a purely scientific or research-based question [...], in the end it's more of a project application rather than a science application"

The qualities described by the scientists were abstract, such as the ability of designers to apply a holistic and systemic perspective to the work they do, and therefore to think strategically about problems. Similarly to Cross's observations about the difference between design and science (1982), interviewees mentioned differences in approach multiple times. Science is considered analytical and focused on details whereas design is seen as taking into account the bigger picture or context. Scientists seemed to value the latter, as it can bring perspective to what is otherwise perceived as a narrow process. In view of this, design's normative and constructive role is being recognised (Cross, 1982), as design is considered helpful in answering questions about the purpose of the research, its goals and direction.

SCI / CHEMARTS

"In science typically [we] study the details, it's often [the] hypothesis, the point where making a research plan begins, but with the designers it is on these bigger things: what should be studied, what questions should be answered"

SCI / PLATFORMS

"[Design could help in] having a more systemic level [of] understanding [...]. Because I think people on our side might very easily focus on the actual details of a system, whereas, if you look at the whole system, why would you even ask that question that you're asking?"

"I really hope it would lead to higher societal impact in terms of [...] the designer partners helping us to see our work in a more general context, and then maybe pinpointing things where it can actually relate to the society and society's problems"

INTEGRATING DESIGN METHODS

I have mentioned above how the thinking processes of designers have been considered valuable in the collaborations, as they provided a systemic perspective. In that instance, such a thinking process can be considered a design quality or skill, but it cannot be considered a method in itself. However, other structured design methods were cited. One case was the Materials Platform, regarding the way they work as a team, and the projects they lead. The manager explained that they apply design methods to most of their work, citing specifically "process design". However, this was not mentioned by the designers in the team, which might indicate different understandings of design and its methods or an underestimation of the design contribution from the designers' part. In either case, it exemplifies the fuzzy borders of design and the difficulty of identifying what can be specifically attributed to it.

MNG / PLATFORMS

"[They] both have design backgrounds but in not just visual design, but also process design. And in that sense they help streamline the actual work that we do as a team, in addition to trying to help these collaborative research groups find ways to work together more efficiently. [...] It's also applying design thinking to funding requests."

In another case, a collaboration for a research funding application exposed a researcher to design methods.

On that occasion, the designer provided a helpful point of view thanks to their knowledge of co-design methods. The scientist, who was already interested in how different methods could be applied as part of the scientific process, recognised how the designer helped them in thinking about the methodology section of their proposal. Although it was not a formal use of design methods in scientific research, it sparked new ideas.

SCI / PLATFORMS

"I would really like to use co-creative methods and really engage people who are still practicing that type of cultural heritage [which the scientific research draws from]. But how to do that in a respectful and culturally conscious way? So those are the things that my colleagues wouldn't think about, almost at all. And he [the designer] had a lot of points of view [on] that. So that, substance-wise, I find it very helpful."

5 - 2
Benefits

Outward			Inward	
Connecting with the public	**Connecting with the academic community**	**Connecting with stakeholders**	**Facilitation of research**	**Challenging perceptions**
Dissemination of knowledge Accountability	Impact in publishing Visibility Ground for collaboration	Funding institutions Industry, business & NGOs Public as stakeholder	Reflective research Integration of new methods	New perpectives Idea generation

The benefits outlined in this subchapter are the effects or positive consequences of the contributions described above. These mostly build upon and expand notions found in the literature, specifically in Rust (2004) and Driver et al. (2011). They can be divided into two groups: inward benefits and outward benefits.

Outward benefits

Firstly, I describe the outward benefits, which are concerned with connecting the scientific research process with actors outside its immediate boundaries. Three main actors are identified: the public, the academic community and stakeholders. Connecting with the public is especially linked with the dissemination of knowledge and with the idea of ensuring transparency in order to facilitate accountability. Then I identify different ways of connecting with the academic community, such as achieving higher impact in publishing, increasing visibility and establishing grounds for collaboration. Moreover, the integration of design is discussed for its ability to effectively engage various stakeholders, such as funding institutions, profit and non-profit partners, and the public as an active actor.

←

Table 6
Summary of benefits

Inward benefits

Secondly, I detail the inward benefits. These are the ways in which design's contributions affect the internal processes, such as facilitating the research and challenging the scientists' perception. I describe how designers can help the scientific research process to be more reflective and how sometimes designers are able to challenge the scientists' views and spark new ideas.

CONNECTING WITH THE PUBLIC

Dissemination of knowledge

Most interviewees identified the dissemination of knowledge to the general public as a clear benefit of the collaborations, especially those that involved the visualisation of knowledge. In some cases, the collaboration was aimed from the beginning at reaching non-scientists. It mostly took place in the *engaging with the public* phase. Some examples are the exhibitions (e.g. Fragile Water, Materials Matter) and the dissemination projects (e.g. Water Scarcity Atlas). Here interviewees identified as a positive result the visibility that the collaboration brought to the projects and the chance that this visibility could improve literacy among the general public.

DES / PLATFORMS

> "From the feedback we got in Slush [...], people were really enthusiastic and curious and asking questions. Even people that were not so much involved in science. So that's a really good benefit. [...] that people would gain knowledge."

DES / DES-INSIDE

> "A researcher, when he or she publishes something, it's usually for a very limited academic circle. So, how I understood from some of the researchers they were really excited to see... could this solve one of their problems, that they are talking such a difficult language, the scientific language, and the articles are hard to read for a common person? Could we help somehow [in] bringing the research [to] light? So that it would be more visible to a larger audience."

Another idea which was introduced during the interviews was that if the visualisation of science is improved at the very beginning of the scientific process, it will eventually have broader reach. In this case, the collaboration does not necessarily produce an outcome intended to connect with the public but could take place, for example, in the *publish* phase. The hope is that if a scientific finding is effectively communicated in the scientific paper, it will be more easily picked up by the general media.

MNG-SCI / PLATFORMS

> "If you have a top journal article coming out, or you're preparing a manuscript, of course we don't know if it will be published or where does it actually go. But if you're aiming high, contact us, and we can see what we can do in terms of delivering a more polished visualisation, to better communicate your results, but also act as kind of a catch for the public media."

Moreover, the researchers were personally challenged to communicate their work. Through the process of collaboration, they had the opportunity to think and talk about their research in more accessible terms. Besides the benefit of eventually having visual artefacts to connect with the public and spread knowledge, the collaborations also stimulated the scientists to reflect about their skills. This was also recognised as a benefit.

SCI / PLATFORMS

> "I think [the biggest potential of these collaborations] is building skills in thinking about problems in a way that's suitable for a broader audience."

SCI / DES-INSIDE

> "It opened my eyes [to] how much I actually need to explain. So maybe in the future when I try to explain,

let's say I try to engage with the public, I can really start from the basics and the fundamental reasons why things go the way they do."

Accountability and societal role

While many interviewees discussed the connection with a broader audience in terms of improving awareness and literacy, some pointed out how reaching the public is also a responsibility to society at large. As Aalto University is a public institution, it is part of civil society, and Finnish taxpayers fund its activities. Through this lens, ensuring the accessibility of the research is a necessity for the transparency and accountability of the institution, which can also be achieved through clearer communication. This notion is relevant to the relationship between places of knowledge production and society, and it seems to move away from a deficit mindset (Bauer et al., 2007). However, although it might be considered a step or a necessary condition towards engaging the public, it is still far from it.

SCI / PLATFORMS

"I think that the clearer the message, the clearer the imagery and the clearer the design or whichever form you communicate in, the better it is. And I think this is good ultimately to justify why we do the research to the public."

SCI / DES-INSIDE

"Well, this is more an ideal situation rather than reality so far, but the result should be presented throughout the layers of society. [...] This is a bubble [scientific community], so any kind of communication that reaches the average person, or non scientific people, is really valuable."

CONNECTING WITH THE ACADEMIC COMMUNITY

Impact in publishing

Another benefit connected to knowledge visualisation was that better images in scientific publications would increase their impact. This idea was discussed repeatedly during the interviews, especially with the people connected to the Platforms. They argued that the more clear the images, the more chances of a reviewer understanding the work and therefore of getting published. Even though it can be argued that researchers can already produce images able to communicate clearly enough to the colleagues in their field, an interviewee also pointed out that "the further you want to go from your closest research friends the better visualisations you need to have". In view of this, design is seen as a competitive advantage when submitting to higher impact journals, where the competition is very high. Furthermore, the visualisations made in collaboration with designers are perceived to be of higher quality compared to what they usually produce, similar to what Cheng et al. (2017) found in their research.

SCI / PLATFORMS

"High-impact papers are not just the papers that have a lot of measurements, or nice measurements, but high-impact papers are the ones which are able to communicate to readers something very clearly."

MNG-SCI / PLATFORMS

"If you can make visualisations that are easy to understand, the more people even in the scientific community will be able to understand your idea. Actually, if you think about how we read scientific articles, quite often I browse through the abstract, but I rarely read through the article, I look at the pictures. Does it have data or things that are attractive to me? And if there is, then I might start looking around it."

It seemed that clarity was a significant parameter to judge the quality of the images and something that designers could provide. However, the aesthetic component was also mentioned as a way to catch the attention of the reader. The same idea of higher impact was mentioned, but this time the image did not only serve the function of providing understanding, but it also acted as a visual hook to make the reader stop and look further. A "good-looking" image would differentiate a paper, and it would be more easily transferred to the public media, as well as possibly used by other researchers in their work. This mechanism would improve citations and therefore, the impact of the research.

MNG-SCI / PLATFORMS

"One thing that I noticed was that when I started to use professionally taken photographs in my articles and I had good visualisations, the publisher selected my work as the highlight thing, or to be presented in their popular news media site."

"If you have good looking images with a good visual story, you would be very happy to utilise that in the reviews and that's a way to get more citations. People are more likely to present your work in their publications. [...] So that's a way to get your science seen by more people. To get more impact, without actually [doing a lot of work]. It is about maximising the potential of your research."

Visibility in the scientific community

Bringing visibility to scientific work does not only mean publishing in high-impact journals. It can also mean creating connections through events and other kinds of communication opportunities in the academic community. These moments create visibility for the projects that otherwise they would not have. Some examples are exhibitions or events held on campus. It was mentioned that the materials prepared in collaborations with designers for such occasions were helpful to researchers in promoting their research in more than one context. As a benefit of the collaboration, they were themselves also able to communicate better to different audiences.

DES / PLATFORMS

"You can see, through visualisations, how you can affect scientific careers, how people get invited to talks or even get excited about opportunities. It feels very random, what good comes from it, from one case it's difficult to see the pattern. But they are continuous small things that happened."

SCI / CHEMARTS

"Of course for me, for example, this has brought much more visibility of what I'm doing. [...] The design people are often much better at communicating everything, so it brings much visibility. Also, [...] I can see, in very concrete ways, how I'm able to present something to different audiences when I collaborate with designers. They do, for example, prepare the materials with me so the quality is much much higher. That can help me also in promoting what I'm doing in this science part."

DES / PLATFORMS

"[The scientists] were interested and enthusiastic for the whole exhibition. It made them interested in the other scientific projects, because they were displayed in a different way."

Ground for collaboration

Another concept that emerged from the interviews was that improving the quality of communication can have benefits for collaboration. On the one hand, clear and compelling images expose a message to more people. This increased understanding might render the work more accessible to researchers outside that discipline as well. In this way, connections between disciplines might be found and created more easily. According to the interviewees, even disciplines that seem very close have very different languages and might have a hard time collaborating.

On the other hand, the very fact of working with designers to create visualisations already exposes the scientists to another discipline: design. This experience in itself promotes collaboration, and it might even be the first time for the people involved to work with someone from a different background. It could introduce them to collaborative working practices and improve interpersonal communication skills.

MNG / PLATFORMS

"So it would be great for us to have university-wide services, rather than department-based services, such as these types of visualisation [...] that are in depth promoting cross-disciplinary communication and collaboration."

SCI / PLATFORMS

"It's only field specific, people in that field know that language. They have their own jargon. But this already becomes challenging when you work with other people. I work now with electrical engineers, and we run into this all the time. We need to get out of there. Because the new information is not found in a specific field, [it's] found [at] the interfaces."

DES / PLATFORMS

"Well, maybe one thing that's worth saying is the disciplinary meeting point that this provides. Because I have a feeling that [...] these scientists have a little bit less experience with that [working with someone from a different background]. So it's a bit of a shock to them, but I think that's good, to be exposed to these things. And then they might also learn skills of how to do this kind of collaboration. Which then they can take forward in their research."

CONNECTING WITH STAKEHOLDERS

Funding institutions

As mentioned in [5-2 Contributions], one of the activities in which designers were often involved was grant application writing. It seemed that many of these collaborations were experienced positively, especially for the scientists who attributed part of the success of specific applications to the collaboration with designers and the visualisations they created. One of the reasons mentioned was the fact that the people working for funding institutions are not necessarily experts in the disciplines of the applicants. This seems to be more relevant the more significant the grant, for example at the European level. If this is the case, being able to communicate efficiently is a skill that becomes even more crucial.

MNG-SCI / PLATFORMS

"The grant writers, in the next spring, [asked] 'can we kindly continue this visualisation thing?'. [...] We can see clearly from this how the visualisations actually had an impact from the feedback that the evaluators gave."

DES / PLATFORMS

"The thing with these grant applications [is], they're evaluated by people who are experts in something, but not in your thing. So you still need to be able to communicate across, outside of your discipline"

SCI / CHEMARTS

"Often because the communication is improved, it has led to situations where we have been able to get external funding more. We had for example this research project. It was this visualisation of what we planned to do in this collaboration that gave us the funding. So we could not have got that funding without the collaboration with design."

Similarly to the benefit of, through excellent communication, being accountable to society at large, it was also mentioned how being able to easily share results could improve the relationship with funding institutions after the funds are granted. At the moment the requirements for reporting are not demanding, according to an interviewee. Despite that, they saw a chance for improvement.

SCI / PLATFORMS

"At the moment they don't ask for much in terms of reports, when we get money from the Academy of Finland. [...] And they're not specialists in our areas. If we can show to them, hey we are doing cool research and they understand it, I think that's a huge plus."

Industry, business and NGOs

The impact of research could also be interpreted as the impact it has on society and how it is able to translate theory to practice. Part of this process has to do with connecting with for-profit and non-profit stakeholders. Some interviewees have attributed to design the capacity to attract stakeholders and to provide tools to engage with them. For example, the Water Scarcity Atlas was showcased at the World Water Week in Stockholm, which is an event attended by many governmental organisations, NGOs and businesses. The researcher, who was there for a week presenting the Atlas in a stall, reported finding it a useful tool to talk to people about his research. Another positive example is the Materials Matter exhibition, which a designer said created an interest among companies. Here the goal was to attract people, rather than supporting learning and understanding, which was the case for the Atlas.

DES / PLATFORMS

"Of course there were many investors in Slush [...] several companies were interested in financing some of the projects. I definitely think that the design and the setup really attracted people."

While these cases were successful in explaining and communicating research, other researchers mentioned how a lack of good communication could be problematic in interacting with stakeholders. They explained that if they are not able to relate their research to practical settings, it is likely that it will not be funded and supported. To them, this is important in terms of funding and also, maybe more so, in terms of societal impact.

SCI / PLATFORMS

"We were Monday in a meeting, where there's three of us presenting to a company. [...] We had this one older researcher, he's been doing twenty years of the same stuff. He was showing [such] complicated graphs, [...] and he's an extreme expert [in] his field, but he was giving a scientific presentation. And he's wondering why the companies never want to invest anything into his work. The companies have no idea how [it's] related to anything that they do. So of course it's more complicated for them to understand."

SCI / DES-INSIDE

"For us it's extremely important that the stakeholders and the public accept our results and our project. We are not dependent on the scientific community alone. [...] We want to produce something useful for society. Sometimes scientific studies produce knowledge which itself is valuable, but the practical value of that knowledge is sort of lost."

The public as stakeholder

An interesting question emerged from one of the interviews: can design help engage people in the actual making of scientific knowledge? As in Mode 2 of knowledge production (Gibbons et al., 1994), the public is viewed as a primary stakeholder, an active contributor to the scientific process, and not only as a one-way recipient of top-down communication. Focusing only on producing knowledge inside and for the academic community was criticized. The researcher reflected on the possibility of collaborating with designers to engage the public in different ways, through communication as well as co-creation methods.

SCI / PLATFORMS

"What I would aim for would be the actual societal impact, not just having higher impact papers that only the professional community will read. Getting more people engaged [...]. Identifying forgotten groups of people and how they could be engaged [in] science."

FACILITATION OF RESEARCH

Reflective research

Rust (2004) argues that constructing visual representations can give researchers a comprehensive view of their work, which allows them to reflect on it and unlock their tacit knowledge. As already mentioned, a significant part of the collaborations I have researched revolved around the production of visual knowledge, therefore I was expecting to find some confirmation of Rust's idea. It was indeed part of what the interviewees considered a beneficial outcome of the collaborations. In some cases, being presented with a visualisation of their research findings, questions or plans prompted reflections among the researchers. They recognised the potential that the visualisation of knowledge has to reveal new perspectives on their work.

MNG-SCI / PLATFORMS

"Visualisations of the research question could be something that 'oh, I hadn't thought about it in that way'. Because usually those are only described in the text."

SCI / PLATFORMS

"I think it helps the science itself be more reflective and I think the more we are forced to think about our own work from different angles and different aspects, the more we realise where the holes are in our current understanding, in our current thinking."

However, it was the process of making the visualisations which was mostly cited as beneficial. These were the cases in which the scientists perceived the designers as part of their team, sharing ownership over the results. Creating the images seemed to be an integral part of preparing, for example, a research plan. The collaboration helped the scientists refine their ideas and seemed to affect the results. Then it was not a visual element added on top of an already written work; it was part of the work. Both researchers and designers contributed to the outcome, interacting and mediating, and affecting each other's thinking. In some cases, this process could even be described as a co-creation process.

DES / PLATFORMS

> "It's not just about making an image that represents a work that's already been done, but it actually affects the way they think about the work as they're still doing it."

SCI / PLATFORMS

> "This was actually a tool for me. [...] If he would have not given me the notes, I would have not been able to improve the paper. It was kind of like a brainstorming."

SCI / WS-ATLAS

> "There was a sense of re-interpretation of the entire analysis of what we've done. And part of the analysis was actually new as well."

Moreover, achieving clarity of thought through this process was a benefit which was often discussed by scientists. Thanks to the interaction with designers, by having to explain their work to others, their understanding became eventually deeper. A sense-making role, in this case, was instrumental. At the same time, assuming an outsider role was also contributing to the reflection, because, as one designer put it, "now they have been confronted with what other people do not understand".

> "There's a saying, you don't really know something unless you can teach it. It's the same here, you can't truly understand something unless you can communicate it, visually in these ways as well. I found that very useful. My clarity of thought about some of our work has greatly improved."

SCI / WS-ATLAS

> "I think we as scientists could learn a lot from having to communicate our way of work to others. In doing so we could do better science. Because we realise, we understand our own work better, because we're made to reflect on it."

SCI / PLATFORMS

> "It very much showed, specifically in these couple of cases that I'm thinking of, that it was about helping the researcher make sense of their own work"

DES / PLATFORMS

Not everyone I interviewed agreed that design is directly informing the research in terms of content, nor that it necessarily should. When asked about their role in the scientific process, a designer clearly stated that they are not involved in the early stages of research and questioned whether scientists would want that:

> "Not really. That's not my job. Usually they already have research questions. [...] If I'll start saying, I'm going to help you with your research question, that's not the thing that they want from me. They're professors with

DES / PLATFORMS

dozens years of experience, they don't want to hear that I'm going to help with the research question."

Integration of new methods

A way in which designers can facilitate the research process is also through applying design methods to the research itself. This topic came up during discussions with the interviewees only in terms of potential. One designer said that if the collaboration permits it, they might use that occasion to suggest the integration of design methods. However, while the application of design to all aspects of academic work was described by a research manager as "ideal", this is still far from common practice.

DES / PLATFORMS

"We start with the areas that are understandable and familiar [...] and with some of them we go deeper. We talk about experimental parts and how some of our tools, design thinking, can be adapted for their proposals. But it's still quite on the visual part."

MNG / PLATFORMS

"The potential is to have a designer in every research team. Period. From classroom work to individual grants, to consortium grants, to just testing out new teaching approaches. But to have a designer in every research project would be ideal."

CHALLENGING PERCEPTIONS

Rust (2004) as well as Driver et al. (2011) argue that being exposed to the designers' representations can also challenge the researchers' perspective and spark new ideas, possibly paving the way to new research directions.

Perhaps a step further than encouraging reflection and promoting understanding, in this case, scientific research is being advanced. The only example of such results in a collaboration is CHEMARTS, in which designers are part of the whole scientific process. However, it has been mentioned by others as a potential outcome if collaborations were to become more integrated throughout. For example, exploratory information design could show scientific data differently and provide new insights, or having designers work with doctoral students could challenge their thinking process.

SCI / CHEMARTS

"It affects, or may affect [the scientific research]. For example, from work that design students have been doing in CHEMARTS, they've made some observations that are scientifically interesting, and therefore when they have done this kind of observation, it can form a new topic to study scientifically."

SCI / PLATFORMS

"I understand a PhD process, as a development of [a] thinking process. [...] Imagine if they would work for years in a team [where there is] a designer. Imagine how their thinking could progress. [...] How can I influence their thinking so that they get as much as possible influences from other places? And they get challenged?"

DES / PLATFORMS

"I think if the placement of design would shift up in the process, or maybe more of an exploratory visualisation of the data, maybe it could have even more of an impact where it might show insights that were unexpected or not visible."

A designer also reflected on the possibility that, even if challenged and exposed to a different perspective, a researcher might not act upon it.

DES / DES-INSIDE

"I see that [this researcher] that was there at the opening, she gave a very nice talk and that she really appreciated the work, and that it was inspiring and that it was opening up different perspectives to their work, but I don't know how much this went into a full loop of informing their research to do something different."

Regardless, working with people from a different background can challenge the overall perspective of those involved, not only towards a specific scientific topic. For a researcher involved in a collaboration for many years, that was the most rewarding benefit.

SCI / CHEMARTS

"The biggest thing is maybe that it has opened a new world to me. I can see everything not only in one angle, but from different angles. I have met different kinds of people, [and it] is very interesting to see that not all people are similar.[...] Because the competences are different. Because in science people often are quite similar and they have similar views. So it's enriching, and makes the work more interesting."

5 - 3
Barriers

There are various elements that can act as barriers to design-science collaborations. For example, Rust (2004) cites the designers' contribution not being valued and recognised, and Driver et. al (2011) mention the lack of a shared formal language or the scientists' lack of knowledge about designers' skills. In this research I find some similarities with the literature, however I mostly provide a new frame to investigate the issues that emerged in the interviews.

Time and budget

The first and tangible barriers that I describe are the ones related to resources (time and budget) and practical collaboration dynamics (trust and communication). Understanding these issues, which were very often discussed by the interviewees, seem to be central in uncovering other, deeply rooted, cultural and structural barriers.

Disciplinary identity

Among these, I have identified the topic of disciplinary identity, or the way in which a disciplinary culture, language and approach to knowledge production can affect a collaboration.

Knowledge about design

Furthermore, another barrier is found in the lack of knowledge about design and its methods, which influences the collaborators' expectations.

Organisational structures

Finally, I take into consideration organisational structures and how they might not be fully equipped to support this type of collaboration.

TIME

Last minute timing

In the case of the Materials and Energy Platforms, the timing was a significant issue. Especially at the beginning of this experience, scientists would approach the platforms very late in the process. Sometimes they would request help for the following week or even the following day. Clearly, in most of these situations, the Platforms were not able to help them. Moreover, incorporating design in the very last step of the scientific research process yields fewer benefits. For example, it might preclude the possibility to inform the research or challenge perceptions. In time, the Platforms established systems to inform scientists on the time requirements of the design process.

DES / PLATFORMS

"I think one of the biggest problems is that scientists want help right away, right now, and there is no time to find someone."

MNG-SCI / PLATFORMS

"One of the hindrances in these collaborations is that scientists realise the need for these visualisations quite late. We had some requests, 'we need these visualisations tomorrow'."

Informing the scientists about what to expect improved the situation, indicating that the issue of time might be partially connected to the one of expectations; however, there are still some barriers connected to elements out of the researchers' control. For example, the amount of work they are subject to or the demands of the publishing process. There is much uncertainty in the scientific process. For example, people might not be willing to invest in a paper before they know if and where it will get published.

MNG / PLATFORMS

"And the time-deficit perception as well as the demands on the time of most of our researchers that we interact with, there's just no way for them to plan ahead."

DES / PLATFORMS

"It's a long process. They never know when it will end, when they will succeed. And then of course they might not succeed at all. So, starting this journey together with the design process is time and money consuming also for them. So they don't want to spend [...] resources."

Time deficit and priorities

Researchers in Aalto, especially professors, are very busy, making it difficult to fit in collaboration when it is not already integrated into their practice. The work that goes into a collaboration is perceived as an extra task, as not central and therefore is not often prioritised. There seems to be an underlying assumption that the production of visual knowledge is not central to scientific work, as will be discussed below in the section on the discipline's ethos. This perception can lead to less investment of time and effort.

DES / PLATFORMS

"The professors in Aalto don't have time at all in their agendas. They're super busy. [...] I think it's adding something to their practice."

SCI / PLATFORMS

"It's not the typical scientist that would be good at visualisation. The other problem is that we're not good and we don't have time for that. So the place where we cut the corners is the visualisations."

Consistency

Interviewees reported the difficulty of sustaining these collaborations over time. They require consistency of people and funding, over a long period of time. Otherwise, the risk is that the experience does not retain any benefits in the long-term. Because these collaborations are often experimental, time is needed to learn, adjust and improve. Furthermore, the designer needs time to understand the scientific topic at hand.

DES / DES-INSIDE

"I think it's really about progressing and keeping on with the pilots. We're making these tryouts but we really need to do it at least three times I believe. So that we have an idea of what really can work."

DES / PLATFORMS

"It's difficult to understand where to start from. And then of course when you learn some basics it gets easier and my creativity flow also gets back on track. [...] I really want to get in the researcher's head and see how it's done! [...] And it takes time. [...] Sometimes we don't have this time."

BUDGET

Extra cost

Tightly connected to the lack of time, lack of resources is a crucial issue as well. As mentioned, the collaboration work is not a priority for the research group and it is not integrated into their regular practice. Therefore there is always a question of how to fund these collaborations and this might be a reason why they do not happen more often, as one researcher said. Research groups must rely on their own budgets, unless there is external support, as in the case of Platforms. The amount of resources one is willing or able to spend limits the extent of the collaboration. Moreover, when working on a paper or a funding application, there is always the risk that it will not be accepted. A researcher speculated that it would be different if a designer were employed full time as part of the university staff, maybe collaborating with various groups at the same time.

SCI / PLATFORMS

"This is actually one of the reasons why we often don't do this. So, if I wouldn't have had the Materials Platform paying for some of this, this would have been an extra 2500€ out of my budget. For the uncertainty of maybe not even getting the cover. And we can use the imagery in our other promotion and talks that we give and all. So this was actually a nice incentive that the Materials Platform provided, that they're covering part of the cost."

SCI / PLATFORMS

"At the moment Aalto doesn't have more resources, except for these funding applications, but I'm a bit sad about that. [...] It's such a different thing to send something to *Nature* [scientific journal] when you have something like that [visualisations made with designers]. When I do something on powerpoint it doesn't feel [like] *Nature* material."

"This is of course a resource question, in the best case scenario it would be of course not maybe a full-time designer, but maybe we could share with two different teams. So that could be a shared resource."

Profitability

The designers understand that scientists may perceive these collaborations as risky investments because the benefit is not always clear, an issue found in the private sector as well. Some researchers I talked to felt strongly that design collaborations are good investments, a competitive advantage. However, others said they probably would not have done it if it were not for the external funding. In one conversation with a designer from the Materials Platform, they discussed how difficult it is to prove and quantify the benefits of their work. At the same time, even if they feel it is a positive investment, the resources are still limited and spending decisions tend to favour large consortia, which might bring substantial funding to the university, rather than investing in projects with individual researchers.

DES / PLATFORMS

"Then they also have to bother to work with a designer, and spend time with them, explaining them, paying them. Then it's eventually becoming for them 4000€, thinking also about the time that they spent. You really need to prove that it is useful. But how can you do it? You cannot really say."

MNG-SCI / PLATFORMS

"If we can allocate one person's work for two weeks, designers are not that expensive in ratio to 2.5 millions. It's an investment, a relatively small investment to potentially get really high gains."

System

When funding is available, and people are on board, there is still the issue of allocating the resources in a system that does not account for the presence of designers. Even if the strategy of the University encourages various forms of multi-disciplinarities, often it is not very easy to include collaborations in budgets. There are many bureaucratic barriers which have to be worked around. For example, a researcher explained that she had to hire designers as "research assistants" and sometimes even that would not be possible. Likely, much design work done within science and technology departments never figured in the official documents.

MNG-SCI / PLATFORMS

"One other challenge is how to fund that kind of work. It's not necessarily the problem of it being too expensive. But projects have very tight budgets. I hired designers as research assistants. For instance, the Academy of Finland doesn't fund any more undergraduate researchers, so you cannot hire a research assistant from that. [...] Last time I applied for funding I was like, but these are not your typical research assistants, these are special research assistants, who would do the visualisations. And they were like, you can put it there but Academy of Finland will delete that amount of money, because it's a research assistant."

Motivation

Talking to the CHEMARTS scientist, they stressed that in order to build a robust and long-term collaboration, money must not be the only driver. In their opinion, a strong motivation is fundamental for the success of the experience; otherwise, when the money is lacking the interest fades immediately. Therefore, the university should support people who are already motivated, not provide funding to motivate.

SCI / CHEMARTS

"Of course some money is needed, but the money itself cannot be the reason to make a collaboration. [...] I think we are not making this for the money, but we need some money for making it. I think often in Aalto we have these platforms and then some money is given to new initiatives, but I think that often they don't lead to anything. Because people are interested when they get the money. But when the money is used, they lose their interest."

LACK OF TRUST AND COMMUNICATION

As with any kind of collaboration, trust and communication are vital aspects. Some researchers have mentioned that the lack of them is sometimes a barrier. On the one hand, they might have exact ideas of what they want and they might not be very open to criticism. On the other hand, some have had the issue of not feeling understood by the designers and struggling to communicate what they had in mind. A lack of common language, discussed below, could be connected to this issue.

MNG-SCI / PLATFORMS

"Sometimes [scientists] have very specific requests. [However] I learned very early on that I just say what I want to communicate and the designers come up with the visualisations to match it. Sometimes we think too far [ahead] ourselves as scientists, what we want and then we don't have room, we are stuck with our own idea. That's also one barrier."

SCI / PLATFORMS

"What I think also is extremely crucial is that there is that skill-set but also just the communication. [...] They're [scientists] extremely sensitive to what they perceive as criticism."

SCI / PLATFORMS

"So the challenge specifically with designers is [...] sometimes at the beginning it was not so easy to communicate our ideas of what we thought our design could look like."

An instance of lack of trust is when the scientists are unfamiliar with the design process, or the designers with the scientific process. Designers reported cases in which the lack of trust was so significant that it would hinder the positive outcome of the collaboration. It might be that some researchers did not have any personal motivation and did not think it would be profitable or helpful from the start, in which case it is very challenging for designers to convince them otherwise and the results suffer. This issue could be connected with the one of familiarity and expectations, explored later on.

MNG-SCI / PLATFORMS

"Every time you have to start this talk, what design can do, and then of course if you're not proven with what you do, it's very difficult for them to really trust. Even though we all have here a trustful environment, it's just a thing. It's human nature."

DES / PLATFORMS

"Those who are like 'this is a drag why are we even doing this, why don't you understand what I'm talking about', with that you're starting with such a disadvantage that it's hard to then make up for it."

DISCIPLINE'S ETHOS AND LANGUAGE

Scientific academic culture

An underlying theme to many discussions was the culture of technical and scientific disciplines. The ethos, or the collection of practices, beliefs and customs that characterise academia, was sometimes blamed as a barrier to collaboration. Words such as "traditional" and "conservative" were used to describe a culture that is not always predisposed to outside influences. A scientist argued that it might be a mindset that goes back to education. Therefore, it is challenging for practising researchers, whose disciplinary identity is deeply rooted, to navigate a multi-disciplinary space, as argued by Gibbons et al. (1994).

SCI / PLATFORMS

"Other challenges that I've really noticed is that people are very traditional. When you're trying to propose these things, and you cannot show them the numbers or concrete things."

SCI / PLATFORMS

"Yeah, it's challenging. [...] I think it's a question of science education, because[...] if you have a short project, five hours working together, you can't change the mindset of the other person. I think that's also something we should develop in terms of science education, how to train people to be more open to collaborations."

DES / DES-INSIDE

"It's a surprisingly conservative world. [...] You're on the forefront of human knowledge and so on, and it would seem that people working there would be sort of keen to experiment on other things than just, you know, what they're experimenting on, but then that doesn't seem to be the case."

One belief or assumption of scientific culture seems to be that design is not as valid as science. Firstly, design is often only associated with graphic design. Visualisation skills are considered "soft", which, in that context, carries a negative connotation of being secondary, of visual knowledge being intellectually inferior, as pointed out by Cairo (2013). In some cases, visual design is even considered as unfavourable. From that perspective, it might taint or skew the content, which is considered as separate from its representation, and meaningful above all. As one designer reported they had been told, "this is not propaganda, this is science". Secondly, academia has many norms for knowledge production, which apply to visual knowledge as well. Only certain graphical forms are accepted and everything that does not conform to the conventional and the traditional risks to be questioned as not "objective" or "scientific". Designers discussed the difficulty of navigating such a rigid system. Finally, there seems to be an overall lack of knowledge about design processes and methods. This topic will be discussed more in detail later on; however, it is important to note that a narrow idea of design seems to be widespread and it might, in part, influence the sentiment towards it.

DES / PLATFORMS

"The way we were trying to ask them to explain things to us felt too simple for them, they were saying "this is not propaganda, this is science". I know, I understand their fear because of course they're scrutinised and they need to live up to a standard, which is also my goal, to help them do that. But I felt a strong push-back when we would try something. Either that's too simple, or then different from how things are usually visualised."

DES / PLATFORMS

"When we had ideas on how to present the research, sometimes the scientists were a bit upset that we would simplify too much. Because it's such huge work and it's much more complicated than the final visual object. At some point they were telling us to not go too simple, or too elegant, too beautiful, because it was not exactly what that was supposed to be used for. Not just to be beautiful but to have a real use. [...] They just want to be sure that the content is more important than the final look. And for us the look was so important, for the people to first be attracted to the piece, and then read about it and learn the scientific benefits."

SCI / CHEMARTS

"I'm not able to talk about what design people think about scientists but scientists often have a quite narrow view on design. And maybe they might think that science is more important than design, and that is not a very good starting point for the collaboration. I think that actually when we had some big research project, in the beginning, we had this kind of problem also. We had this project where Aalto and VTT were the main partners. And in this big consortium design had in the beginning a really small contribution. And I think that most of the people in that consortium in a way thought that science is more important than design."

Science-design collaborations, some more than others, have brought researchers in a space outside of their usual academic culture. In such "middle spaces" or "interfaces", the conventional roles and rules are different, and as mentioned above, that can be an uncomfortable and challenging experience. A designer suggested that they are used to operating in those spaces, while scientists are not. A researcher also argued that it is especially tricky for professors as they usually are in the role of "experts", transferring knowledge to others. However, in multi-disciplinary collaborations, they are forced to reconsider their role.

DES / DES-INSIDE

"I really like this idea that design has this mediating role, [...] and we actually enjoy being in this middle space, quite a lot. Because we like to discover things, we like to integrate it in our own research. So I think drawing people to this middle space is a challenge, but it's a nice place to be, I like that space very much. But I don't know if scientists like that space of uncertainty."

SCI / PLATFORMS

"It's challenging all the time, and it's always challenging for the researcher, because you have to take a leap of faith in order to go there. Because we have this problem that we want to be experts, that's our definition. Professors are experts. And I'm a professor who is all the time out of her comfort zone. That's horrible! I'm never an expert on anything! [...] It's really healthy for me, but I can understand that it's very challenging for many of my colleagues. And it feels uncomfortable and it feels unpleasant."

Hierarchy

Another aspect of academic culture that was mentioned multiple times is the hierarchical system. Such a system might not be able to accommodate collaboration, leaving the designers to find their place in it. In the case of the Platforms, the designers were often master students, which meant that researchers associated them to the master students in their field. As this meant being subordinates in the hierarchy, designers mentioned it as a hindrance to the collaboration. For example, being seen as a subordinate puts designers in a difficult position when proposing new ways of presenting information, giving feedback or criticism.

DES / PLATFORMS

> "Maybe the set-up in their own fields, where there's the hierarchy and you've got the professor, and they've got people underneath to do work for them, post-docs or doctoral students and then master student are the bottom of the ladder, and you tell them what to do and they go do it in the lab."

DES / PLATFORMS

> "I think, especially when you work with professor-level people, there is this kind of ego problem where, obviously they're very smart people but they're not the best communicators. But some of them have a really hard time taking that in as a fact. And so that would obviously hinder the [collaboration], because they would kind of resist."

Language

Knowledge in different disciplines is expressed through specialised language, and when they collaborate and do not share that language, it can be problematic for all involved. On the one hand, it is about discussing new ideas emerging during the collaboration. Scientists might lack the terminology to express what they have in mind in terms of design. On the other hand, the use of scientific language might be a barrier for the designers in understanding the topic they are working with.

SCI / WS-ATLAS

> "[A barrier is] not having a common language to talk about design. At the end of our pilot there were still things we misunderstood. And we did put a fair bit of work into trying to communicate what we wanted. I did draw wire-frames with them to discuss the kind of things we were trying to communicate. But part of it was that substantial parts of the large website we didn't actually have things for yet. So naturally trying to communicate that broader vision when what we had was a narrow set of data... it took a while to get on the same page for that."

DES / PLATFORMS

> "I think understanding their material was sometimes extremely hard. Because, you know, I am an outsider. I think that you can write in a way that is easier to read, and a lot of them kind of lean into the acronyms, into the jargon, burying themselves under so many layers of question marks that it's really hard for someone to understand."

SCI / PLATFORMS

> "The language that we speak in the different disciplines is very different. Oftentimes we have to communicate about very specialised knowledge to actually advance our projects. Those that don't speak this specialised language are often left out and then it's a challenge to integrate everybody."

Approach

While the differences in approaches to knowledge production between science and design (Cross, 1982) can be beneficial, they can also be a barrier. A designer suggested that it is possible to learn from each other, however another interviewee also pointed out that mediation might be needed in order for the collaboration to be fruitful.

DES / DES-INSIDE

"I think that artists and designers think we make a wider impact to the public, because we reach more people or more deeply through different communication channels that are not scientific but can be emotional, experiential or like that. Whereas hard data or findings that are real and proved are the way to speak with scientists. These are the ways that they kind of read and understand. But of course scientists are humans also so I think they can also have this sensibility toward the embodied or the conceptual or the experiential."

DES / DES-INSIDE

"I guess this different way of thinking, that designers have this super holistic approach, that is hard to [explain], because you see everything as 'everything is interconnected', whereas an engineering mindset is more about breaking things into the smallest possible pieces, and then working on those. So probably both parties need to rethink their approach a little bit for the collaboration to be successful."

FAMILIARITY AND EXPECTATIONS

What can design do?

Expectations about the collaborations are usually connected to preconceived ideas of design. Some interviewees reported that many scientists think that beautifying is the sole purpose of design, to make something "shiny" and "pretty". This barrier, which is also cited by Driver et al. (2011), has been significant and challenging to overcome. However, some researchers that have approached the collaboration with an open mindset seem to have formed a more complex idea about design. Nonetheless, they might identify the scope of design only in one frame, as, for example, communicating with non-scientists. While that is indeed a valuable contribution to the research process, it is only a first step in thinking about various ways in which collaborations can have an impact.

MNG-SCI / PLATFORMS

"There are also these cases where we had for instance some slides and someone sent them to a designer [asking] 'oh, you can make them pretty'. We don't want to make them pretty and you cannot suggest anything that goes more in depth, to actually change the visual communication beyond having reasonable fonts and colours. If you don't speak to that person you can't understand what they're planning to tell about that particular topic. [...] But I think there is this misconception that design is only making things pretty. It's not about that, it's about making the visualisations effective, changing the communication."

SCI / CHEMARTS

"I think that was the case, that most of the people in that consortium in a way thought that science is more important than design. [...] It is coming from the fact that they don't understand what design is."

SCI / PLATFORMS

"[When] doing your own research where you quickly visualise some info yourself to understand your results better, it doesn't have to look stunning. It just has to be clear in what it communicates. So I think the different clarity of communication is always good, [the question is] to what degree do we polish it, how far out of the ordinary do you go in making this perfect. So I think that aspect of design we rarely ever have in our work until we really need to reach out."

Moreover, identifying the different ways in which people define design is a challenging endeavour. Nevertheless, the questions of what design is and what can design do emerged often in the interviews. Sometimes, the words art/artist and design/designer were used interchangeably, which could indicate an understating of design where the boundary with art is blurred. Overall it seems that for designers, it is challenging to explain what they do and for researchers to understand it. For example, some mentioned that design is more than just making nice tables and clear communication; however, they were not always able to articulate what "more" is. In one case, a researcher was surprised about the way the designer was able to affect their thinking process. However, they were wondering how this added-value, which is intangible and qualitative, could be communicated.

DES / PLATFORMS

"I think trying to help them understand what to expect is a big issue."

SCI / PLATFORMS

"How can I explain this? I never thought that [the designer] is gonna give me this table, so I could never even understand that instead of me asking him to visualise my message for the ERC grant, he can actually help me understand how to summarise my work. So this was something very hidden, in a way, that I couldn't even understand that it could be happening. This is also the question, how do we market this? How do we see the added value? It's not *just* in the visualisation, it's *also* in the visualisation. This development of thinking is a very abstract process, but we're a university, if anyone we should be able to understand abstract processes. But this is challenging as well, I don't know how to address that."

Design process

Where there are theoretical questions about the definition of design, there are also practical issues. Lacking knowledge about design also means being unfamiliar with its methods and processes. This translates into practice as misplaced expectations about time, outcomes and commitment required. According to the Platforms' teams, it was common to receive requests for help with unrealistic requirements—either with a short time frame or extraordinarily high or specific expectations, or both.

DES / PLATFORMS

"I mean, it's not their fault. But they have no idea of what's involved, how long it takes to do something... Yeah, we joke about it that you know, we're just sitting in a room waiting for them to come and do work for them. Like we don't have a schedule, like we're not busy with anything else, that they can come and ask for their poster tomorrow and we're just ready to do it."

MNG / PLATFORMS

"It also assumes that the focus of all academic research is publication and that's something that's a further barrier here at Aalto is that we have a very technology and science perception of how research happens. When in fact business and arts do lots of research too, no surprise, there's a PhD available, of course they do research. But knowledge about what their processes are and what their ideal outcomes are is also not very well known."

Another issue for the Platforms was how researchers expected to be involved. In some cases, if they expected the designers to carry all the weight, the collaboration suffered. In that situation the definition of collaboration can even be questioned. For these reasons, setting expectations and explaining the process at the very beginning has become common practice. A designer stated that it is not problematic anymore; it has just become an integral step in the process.

MNG-SCI / PLATFORMS

"What does the designer do? The designer won't read your article and come up with [a nice visual]. If you want a visualisation of your work, okay the designer might read through your proposal, but you're still expected to be in discussion with the designer, to discuss what actually to visualise and how to do it. So that was one challenge, understanding what can you expect from the designer and being able to communicate on a level that it actually works."

DES / PLATFORMS

"They want us to do 100% for them, but even though we do most of the job, at least it should be 80-20 you know, but not 100%. They have to at least explain things to us, and it takes some time and sometimes there are projects that are not working very well. There are some times where in the end no one is happy. That's also happening."

"I would say for me it's not a challenge anymore, to sit with them and explain things to them. I understand it's just [an] important part of the process that I go through all the time. Because I realise that without this step, [...] using numbers also in this offer, so they could see it in their minds and believe first in this numbers, [...] the collaboration might not work at all."

STRUCTURES

The university does not uniformly provide collaboration or design services to its employees. It does so through these particular operative units, such as the Platforms and Design Inside. Most of the time people who need design do not have access to the services. Therefore, they find alternative ways to work within or around the existing system. For example, a researcher told me that in their department they "have a designer", a person that "produced quite a lot of visual materials" for them. However, this person turned out not to be a designer, or at least not formally. They are working in communication services and have a background in media and journalism. While I do not know if that is part of their job description, they have created visual material for the researchers to use in scientific posters and publications. I also asked another researcher how they usually produce cover images for their articles, and they said that it is through an informal network built over time. At the moment, there is no official, structured, university-wide design service fulfilling these needs, though some interviewees suggested that it could be beneficial, even though challenging.

"How do you usually find designers, for these covers, without the Material Platform or external funding?"

SCI / PLATFORMS

"That's a good question, I don't actually know. It's I think built up over years of networking and making contacts. And actually just now my colleague who's a co-author on this paper for the last cover, he has some contacts from previous work, but then when he saw this cover. He said.. [can I get in touch]. So it's a lot of word of mouth, and you ask your colleagues and that kind of thing. But I must say that in this regard the Materials Platform list and contacts were immensely useful."

MNG-SCI / PLATFORMS

"That's another hurdle, it would be nice to have Aalto-level professional design help, and I know of one designer that Aalto University has. One, in the Communications. But with that kind of resource it's... She basically does the strategic communication for Aalto. But that's it."

Besides the lack of widespread services, there are times in which structures can hinder collaborations. A clear example is funding. As mentioned previously, allocating resources for designers can be very complicated when the university and funding organisations do not account for it. Furthermore, even establishing collaborations between departments within Aalto can be problematic, as the bureaucracy is not structured accordingly.

MNG-SCI / PLATFORMS

"Sometimes it's really hard when there's boundary conditions from the funding agent. But it's funny because the funding agent would like to see the popularisation of science. It's in their interest. It's not woven into it that you could hire designers. If they understood the whole thing, I think it would be ok, but the system is quite rigid and this is a new thing."

MNG / PLATFORMS

"Something as small as a shared summer student between one school and another school, that student could have two different rates of pay, two different contracts, two different everything. And then they're only 50% in each place and only for six weeks in the summertime. And the sheer amount of hassle that goes into to just get that student started and then when you want to provide actual supervision of the student, and so on and so forth."

5 - 4
Facilitating factors

In this subchapter I describe some of the aspects that interviewees mentioned as supporting or facilitating the collaborations. I have found that most of the facilitating factors are comparable to those studied in interdisciplinary research (Epstein, 2005), as also mentioned by Peralta and Moultrie (2010). Among these, the ones that emerged most strongly from the interviews are: a positive and open-minded attitude, time and trust. I also documented an additional facilitator: ensuring a balance of benefits and stakes among the participants in a collaboration.

POSITIVE AND OPEN-MINDED ATTITUDE

Multiple times during the interviews, people associated the success of a collaboration with the positive attitude of the participants. Being open-minded was often described as a requirement, which can lead to better results and more satisfying collaboration. Moreover, more open-minded team members mean that designers can have the opportunity to be more involved with the core issues of the projects, and to introduce different ways of producing knowledge.

SCI / CHEMARTS

"I have seen that even though other professors have seen how it works, maybe they are not always able to repeat the same. So I've seen that it's how open minded people are. That is required for these collaborations."

DES / PLATFORMS

"I think the most satisfying [collaborations] were the ones where the value was understood from the beginning. [...] I think the people who already come in with the attitude that they are curious and want to learn, they get more out of it and are more happy in the end."

DES / PLATFORMS

"Our approach is, we don't work with difficult scientists. We don't want to convince people and spend time convincing them that we are useful. Because it's still quite a lot of work already, serving those who want to get the service."

Approaching collaboration with an open mindset is also valuable for the designers. An interviewee discussed how, in addition to contributing to knowledge production, it was an opportunity to learn as well. Showing interest in the researchers' experience helped them to be more integrated and engaged.

DES / PLATFORMS

"I also really tried as a designer not only to bring my expertise and teach them about design but also learn from them. I'm genuinely interested in the science part. I think that's also important that they see that I'm engaged with it. It's important sometimes for the designer to participate and get involved in some things and ask questions even if the question is not related to your visualisations per se. They're more about the other person's work and lifestyle or what they're doing. So they see that you're also learning from them."

TIME AND TRUST

Time and trust go hand in hand when it comes to improving the quality of the collaborations. In a positive feedback loop, the more long-lasting a collaboration, the more trust is built, the more the experience is positive and gets repeated. Time is needed to find a common language and to get accustomed to each other's way of working. After collaborating for some time, researchers would be more familiar with the design process. They would understand better the contribution of design, while designers would be more knowledgeable about the research topics and methods.

DES / PLATFORMS

"After they got through one project with us, then it's easier. And they get some results, and they come back for more. If they come back for more it means they got better results than what they were expecting, or a better result than without this service. And that means they have more trust in us."

SCI / PLATFORMS

"I like him, because he does work so close to us that he can understand where we are at. I mean, if we just take a designer from somewhere, it might not be possible. Meaning that he already works in this interface."

DES / DES-INSIDE

"The artistic process is very unfamiliar to research people, many of them at least. To build trust and understanding about how artists talk or about how science people talk. That takes long and it's a challenging thing, so it would need longer collaboration, definitely. So that they have the feeling that they're talking the same language."

MUTUAL BENEFITS AND STAKES

Everyone involved in the collaboration has different goals and agendas, while at the same time is trying to bring value to reach a common goal. Fulfilling these two needs is very important. In many cases, the scale was often tilted either on the scientist's part or on the designer's part. Usually, in the Platforms' case, designers were there to help the scientists reach their goal. However, the Platform team also tries to be supportive of the designers' needs. The opposite happened with Fragile Water, in which researchers were supporting the designers in their artistic process. In that situation, the researchers did not have a considerable stake in the process; they were mostly concerned with helping the students.

MNG / PLATFORMS

"They sometimes supervise those, just to make sure that the designers are getting the most out of this themselves, because it's not all about the customer's wishes, but actually if we're using students they may need some support, or a negotiation partner, in trying to make sense what the customer wants. [...] So, that negotiation, why leave it up to a student designer to have to suffer through what could be perceived to be intense or an unequal balance of power. And then we try to be there. But also to provide a positive experience to those designers we bring in externally."

SCI / DES-INSIDE

"The goal here for the researchers was just to help the students to create something. [...] These challenges are not really challenges in a situation where I don't have a goal."

I observed that many interviewees were reflecting on this balance. On the one hand, everyone wants to feel useful and supportive of the collaboration. For example, a designer was questioning their specific role and contribution, which was very important to them, while another designer said that not being able to pursue their design aspirations fully was frustrating. Also, one researcher wondered whether the designers are fulfilled in this kind of collaboration. It seems that a certain level of mediation and compromise has to be taken into account.

DES / PLATFORMS

"If I have to pick, most important for me is to understand that I could create value for them. I don't want to be useless, just pretending to bring a value. It's a question that I'm always asking myself. [...] I don't want to be an "artificial adding on top of their research. It's difficult to prove to yourself that you can bring the value. That's the most challenging for me."

"There are a lot of questions, I think from the researcher's perspective, they also somehow have their own agenda. I always try to understand it and try to align it with mine so that we can work together. And that's not always the case."

DES / PLATFORMS

"So I think I was intellectually really fulfilled during that time, but I was frustrated as a designer. Because I felt like I could do more, or we should do better and I felt like I couldn't."

SCI / PLATFORMS

"What I always wondered though, and I brought this up several times when these artist/designer-scientist collaborations were discussed in the MP and elsewhere, is like, what's in it for the designer. And actually, are there challenges in say, scientific communication, that are interesting for designers? That go beyond helping the scientist?"

Nevertheless, my research showed that it is possible for collaborations to exist in which both parties have stakes, benefit and thrive. That is the goal of CHEMARTS. The idea is that both disciplines are working at their full potential; they lift each other up, instead of bringing each other down. For that to be possible, in their opinion, everyone has to be very competent in their own field. This is also the only case of an integrated team, which probably makes it easier for everyone to be equally involved.

SCI / CHEMARTS

"It is important that everyone who participates has deep knowledge of his/her own field. Because many people may think that [...] if I work with design, that means that I don't do things at a high scientific level. But that is not the idea. The idea is that I will do everything on my best scientific level and the design person in the same way. It's not compromising your own competence. [...] I've found, it is important that you must be confident about your own competence in order to be able to do things that are different."

OTHER

Interviewees also referred to some other characteristics that are worth mentioning. One is physical proximity, which seems to be a crucial part of many collaborations, even if not explicitly stated. For example, a designer noted that sketching together with researchers helped them to feel more engaged in the process. That would not have been possible without a face-to-face meeting. Moreover, in the case of CHEMARTS, it was discussed how working in the same building can help the process as well as the spread of ideas and learnings.

DES / PLATFORMS

"Especially with some of them, [they] were really happy to draw together or we asked them to bring sketches. And that really helped them, or it helped them feel like it's theirs, not just something coming from the outside."

SCI / CHEMARTS

"Because it's on this person's level, it's easy. We're actually sitting [close], Pirjo is sitting on this other table here. We work almost daily together."

“We have people here all across and we can see what others are doing and we can learn from each other. And that is how it can spread.”

5 - 5
Models of collaboration

In the following sections I will describe how the interviewees related to the collaboration models, which I created based on Juninger (2009), Peralta and Moultrie (2010) and Müller (2018), as explained in [3-2 Data gathering]. The first model describes different levels of engagement of design in a scientific research team, while the second one represents where, in the process of scientific research, the collaborations were positioned. Overall, I found that interviewees identified the most with the models of lighter design integration and they often positioned their experience at either end of the scientific process. Finally, the models often prompted the participants to share their views on a deeper integration of design, which I will discuss in the last section.

MODEL 1: ENGAGEMENT OF DESIGN

Overall, interviewees identified most with design as an *external resource*. It was the most common situation, while there were a few instances of deeper engagement. The three models that present more engagement, from peripheral to integrated, were mentioned rarely. *Part of the team/peripheral* and *part of the team/central* were used in the case of the Water Scarcity Atlas and in some of the Platforms collaborations, especially those that involved writing funding applications. The last one, *part of the team/integrated*, was only used by one of the Platforms managers to describe the internal working of their team and in the case of CHEMARTS.

→ **Fig. 35** Visualisations of interviewees' responses to engagement of design model

MNG-SCI / PLATFORMS

"If you think of the operations of the Materials Platform itself the design was part of the team, and it was integrated in the team. Actually the team was mostly composed of designers."

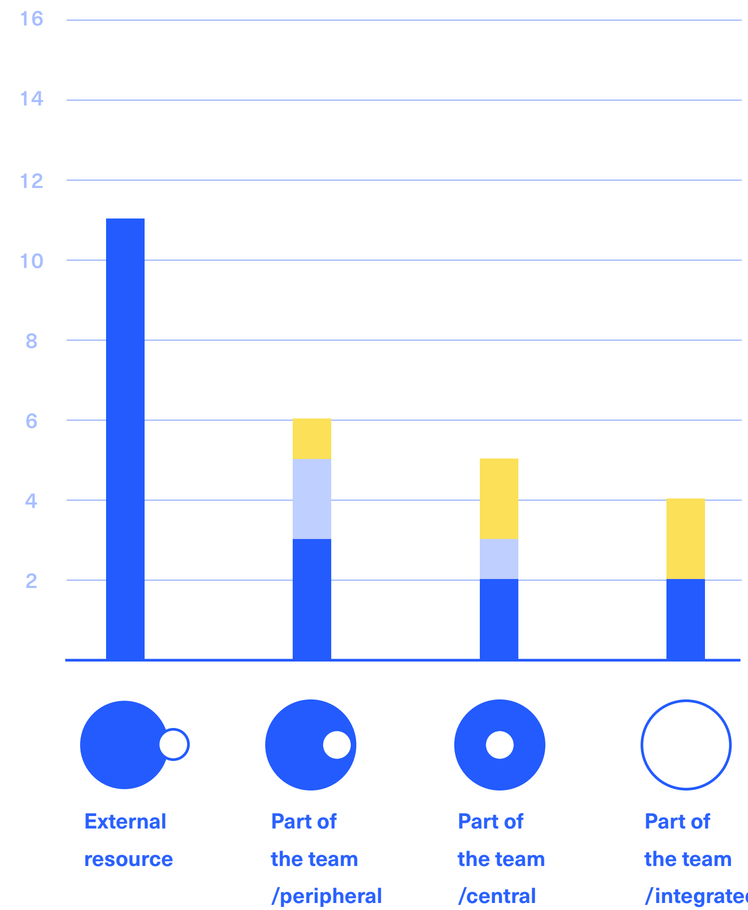
SCI / CHEMARTS

"We are mostly in this [*part of the team/integrated*], typically it's a real collaboration between two disciplines."

When people identified with design as an external resource, they often referred to a "subcontracting" relationship with researchers. The extent of the collaboration was really minimal and the designers mostly worked on their own.

DES / PLATFORMS

"We really came after the research was made. There were the results and then we came up with a



Mentions across interviews

"Have you been part of a collaboration that fit any of these models?"

Yes
Yes, sometimes
Wish

presentation of the results. [...] So it was really like trying to get something from them, not really like co-working."

MNG / PLATFORMS

"Possibly the most common way, is that they're not integrated at all, they're just added at the end of the process. In other words, the process is done, I need a cover for my journal article and I need it in four weeks. The back and forth happens, but that person is not a collaborator, they're just tucked on at the end as a subcontractor, not a collaborator."

However, while the models helped the interviewees articulate the process of collaboration, they were not always representative of the nuances. They raised questions about what it means to be part of a team and how different people perceive it. For example, in some cases, there was a difference between how designers and scientists described the same collaboration. Designers were more likely to see themselves outside the team, while scientists were more likely to regard them as part of the team, even if for a specific project or a short amount of time. Sometimes, it would not be straightforward to choose one or the other, as what started as an external role might, over time, feel more like an integrated one. Moreover, there is sometimes a discrepancy between what the collaboration is on paper, how it is arranged and what it feels like in practice.

DES / PLATFORMS

"I think it's too much to say it's a designer in their team. They just realise they need someone to visualise something. They don't consider designers as part of their team, like, in the long term. At least it feels so."

MNG-SCI / PLATFORMS

"But if you consider the case when we were applying for the FinCERES funding, I think we started from the peripheral team but when we were getting closer [and] at the end it was like the central part. [...] Especially in the second stage, when we needed to have the presentation. The designers were at the very core, they were part of the team and they were in a central role."

DES / PLATFORMS

"I think in the setup that we had it was mostly like an *external resource*. But the way that I would describe that time that we spent together, I felt like I was part of their team. [...] But we're not inside it, we're not from the beginning there. They've accessed us from the outside, in a way."

MODEL 2: POSITIONING OF DESIGN

Overall, most of the cases were concentrated at the extremes of the process, in the *question* phase and in the *publish* and *engage with the public* phases. Clearly, the last two were generally predominant and interviewees easily identified with them. However, in the case of the *question* phase, the association was not as straightforward. This phase was often cited when talking about funding applications, which is a part of scientific research that was not explicitly included in the diagram. The writing of a grant proposal can be considered the first step in undertaking a research process and in this circumstance, a research question is first laid out. Therefore, the *question* phase was the closest association.

MNG-SCI / PLATFORMS

"If you think about making the funding applications, I think it goes more to this very early side [*question*]. Because you refine the question."

SCI / PLATFORMS

"This is interesting because this is a research application, so it's already here [*question*]! [...] How do you formulate the question? How to formulate the hypothesis? How do you formulate this whole thinking process?"

None of the cases saw designers following the whole process from start to finish, except for CHEMARTS. However, some reflected on the fact that, even if the more obvious and straightforward positioning of the collaboration was in one of the two ends of the spectrum, sometimes they engaged more deeply with certain steps of the process.

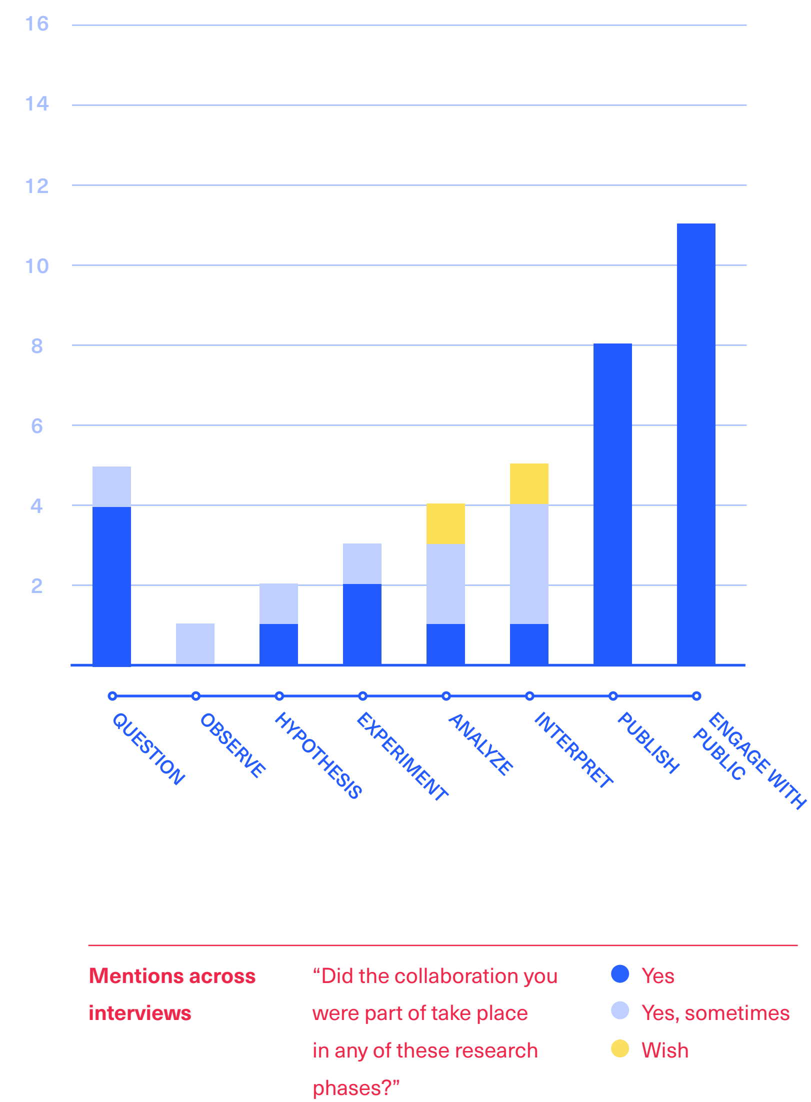
DES / PLATFORMS

"Maybe as far as the *interpret* part, cause publishing is definitely part of it [...]. I would start there with the potential of maybe backing up a little further, but not sure how far."

DES / PLATFORMS

"I would say I would start from here [*engage with public*] and here [*publish*], this is the whole spectrum I can touch. And then analysing [*analyse*] and interpreting data [*interpret*] I think it's quite rare."

Finally, it is important to note that although I have chosen to represent the scientific process as a linear one, the reality is more complex. This was especially clear for the Water Scarcity Atlas case, for which the researcher explained that the process is often iterative. Consequently,



→ **Fig. 36** Visualisations of interviewees' responses to positioning of design model the work on the Atlas, which on paper was explicitly a dissemination project, ended up involving other parts of the process as well, such as analysis and interpretation.

SCI / WS-ATLAS

"It's rarely that kind of linear process for us. We often come back to the question, even right at the end. It's not uncommon to have done an analysis and then to look at, oh wait, it actually answers a different question. So I think, even though this was a project afterwards, [...] I wouldn't say we just were in the *engage with the public* part, there was a sense of re-interpretation of the entire analysis of what we've done. And part of the analysis was actually new as well."

WISHING FOR MORE INTEGRATION

It seems that the models that recurred more often were also related. Most of the cases that were positioned in the last stages of the research process followed the *external resource* collaboration model. People associated more integration of design in the team with positioning the collaboration at earlier stages of the research process. The Materials Platform can be taken as an example, as they are involved in many projects, covering different collaboration models. When asked about the positioning, the manager immediately connected it with the models of engagement. *External resource* would be connected with the last stages of the process, while *part of the team* with the intermediate phases of the process.

MNG / PLATFORMS

"If we're talking about *external resource*, I would definitely have *publish* and *engage with the public.* When it comes to *part of the team/peripheral* for the grant applications, sometimes it's somewhere here in *hypothesis* and *experiment*, but it stays isolated in terms of the contribution that the designer is in the grant application process, so *hypothesis* and *experiment* start, and at the very end *engage with the public*. It's missing all this stuff in the middle. [...] And *part of the team/central* I believe that this probably would happen, I could be wrong, starting with *analysis*. But it could be even earlier, but I would say *analysis* and through to the end. That's if it works."

Sometimes, the *external resource* projects, situated in the last stages of the research process, were seen as "entry points" to promote further integration down the line. It might be easier to establish a short-term collaboration that involves design in more tangible tasks, in order to gain trust and have the opportunity to propose something more abstract later on.

MNG-SCI / PLATFORMS

"It's funny when starting from these points, *engaging the public* and *publishing*, kind of the more logical and the easy steps, we can also see in the board of the materials platform that they were like, let's have designers to help with the visualisation. And then they were like, but how about the research collaboration with designers? [...] You have to start by offering these services, and then they get familiar. It's an entry point. I really saw it in action, with the board. 'We actually could do some science with them!'. But it took a year."

Interestingly, there were many interviewees who stated a wish for more integration. Most of the time, they connected engagement and positioning as explained above, and wished for collaborations across more phases of the scientific research process and that would include designers in their teams. Although they described it as a desirable situation, it was not always clear what the benefits would be, mostly because they had no references for it. The integration of designers in the central phases of the research process is new and the purpose and extent of such integration remain unclear. Sometimes there seems to be an underlying idea of design "in service" of science, which suggests that they might view integration as one discipline supporting another, rather than an interdisciplinary collaboration.

DES / PLATFORMS

"I have seen feedback back from some researchers that it would be nice if the designer could be more involved in the project so that they would understand it better and not come in only at the end of the process. [...] I don't know to what extent. [...] It's one of those things that you don't always think of, when we're thinking it would be good to be able to be more involved but, how much more? It's a tricky question."

MNG-SCI / PLATFORMS

"Myself I would actually like to have designers in my research team, to help with all of this! [...] Because I've seen what kind of added value they can bring. And probably I can't think of all the possible advantages they can bring."

SCI / PLATFORMS

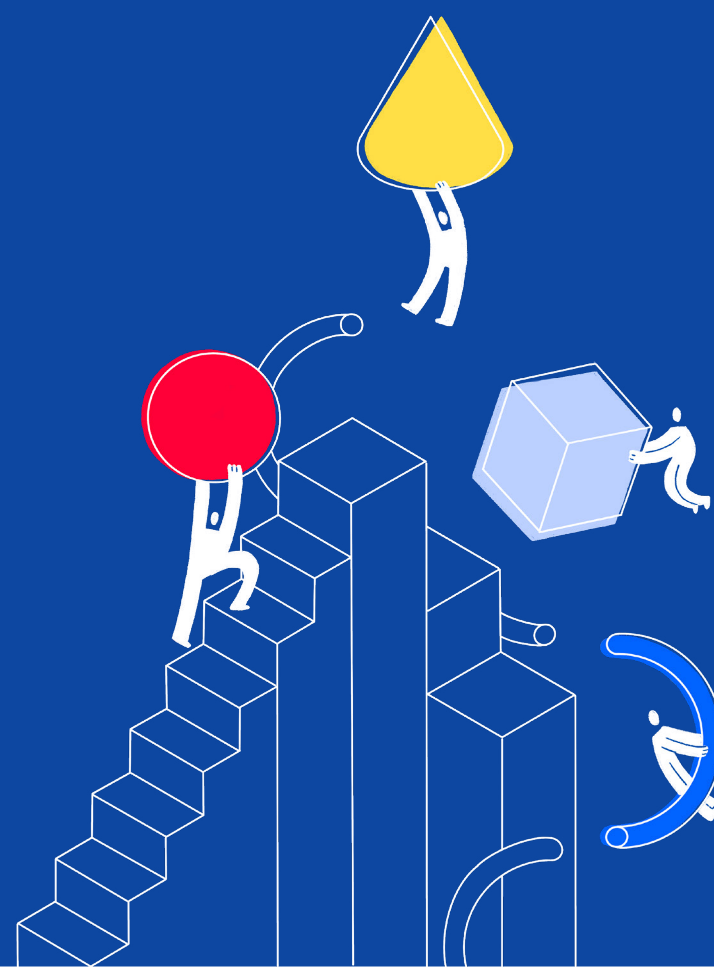
"But I really like this model [*part of the team /central, /integrated*], because then it would be part of the processing, because in this one [*external resource*] we write something and then we have almost ready-made things. Then you want someone to just make your picture look better. That would be a significant improvement of our current situation already, but you know, this would be where they would actually contribute in delivering the message, because in that they're normally much better then we are, or at least from my experience."

SCI / PLATFORMS

"I like the framework, and I think I see it more or less here [*part of the team/peripheral*] and I would have general intention in my group to push in that direction [more integration]. So my wish would be more integrated."

6

Conclusions



6 - 1 Discussion

This thesis aimed at understanding how design contributes to research processes in the current framework of scientific practice. It has done so by illustrating emerging practices of collaboration between designers and scientists in the context of Aalto University and analysing them through an empirical study. In this analysis, I have described the contributions of designers in the collaborations, the various benefits of said contributions and the elements that act as barriers or facilitating factors. Additionally, models were used to describe the collaboration typologies. In the following discussion, I summarize my findings and contributions to the literature reviewed in chapter [2]. My research confirms previously identified concepts and adds new insight into: contributions and benefits, barriers and facilitating factors, and finally models of collaboration.

CONTRIBUTIONS AND BENEFITS

Contributions

Through this research I have identified three principal contributions of design to the scientific research process. These are visualising knowledge, designerly ways of thinking and the introduction of design methods. These categories are not exclusive, but build upon those outlined by Rust (2004) and Driver et al. (2011). A focus on the visual production of knowledge throughout various stages of scientific research expands on previous literature, which has been concerned only with industrial design and applied research (Driver et al., 2011; Moultrie, 2015) or with visual design and science communication (Cheng et al., 2017). Additionally, designerly ways of thinking and doing emerged as contributions to the scientific research process. Interestingly, these were specifically mentioned by interviewees, often independently of tangible contributions. This supports the idea of a shift towards design applied to intangible environments and systems, as proposed by Buchanan (2001). Moreover, Lawson's (2006) and Cross's (1982) accounts of design thinking become relevant in this context. Cross's ideas resonate as, in the interviews, scientists appreciated design qualities such as pattern synthesis, and constructive and normative thinking. Through this lens, design has the capacity to inform how a science problem is conceived, and how a research process is defined. However, the tension between the material and abstract nature of design (Kimbell, 2011) is very much present, since all the contributions, being more or less abstract, stemmed from material practices or were tied to material outcomes.

Benefits

I described the identified benefits as inward and outward. Inward benefits are those directly impacting the scientists themselves and the process of scientific research as it happens within the disciplinary context. These are facilitation of research and challenging scientists' perceptions. Such notions were already present in the literature, however the ones presented here differ slightly. Rust (2004), for example, describes how research can be facilitated through models of representation, which can unlock the scientists' tacit knowledge, and provide an holistic view of a problem. However, in my research, the process of collaboration, in addition to the artefact, were described as the aspects providing benefits.

Outward benefits are those concerned with connecting beyond a research group's boundaries. This means reaching the academic community, from peers within a discipline to those in completely different domains of knowledge, to stakeholders (e.g. industry and funding agencies) all the way to the general public. Here I have identified a further distinction with regard to two aspects. The first aspect, as mentioned in the literature, is communication. The contributions of design can lead to higher impact in publishing (Cheng et al., 2017), dissemination of knowledge (Rust, 2004; Khoury et al., 2019) and improvement in transparency and accessibility overall. These can be considered more straightforward benefits of integrating design, and have been observed by many.

However, a second aspect was also brought to light: collaboration. As explained in chapter [5-3], on the one hand, by experiencing some form of multi-disciplinary collaboration with designers, scientists can acquire interdisciplinary competences. On the other hand, effective

CONTRIBUTIONS	
Designing artefacts for testing and experimentation	RUST (2004), DRIVER ET AL. (2011)
Ideating scenarios	RUST (2004), DRIVER ET AL. (2011)
Finding applications for scientific research outcomes	RUST (2004), DRIVER ET AL. (2011)
Creating technology demonstrators	DRIVER ET AL. (2011)
Performing user and market research	DRIVER ET AL. (2011)
Producing devices/processes/spaces to enhance scientists' research capabilities	DRIVER ET AL. (2011)
Visualisation of knowledge	RUST (2004), DRIVER ET AL. (2011), CHENG ET AL. (2017)
Designerly ways of thinking	
Design methods	

Table 7

BENEFITS	
Unlocking tacit knowledge	RUST (2004)
Facilitation of research	RUST (2004), DRIVER ET AL. (2011)
Challenging scientists' perceptions	RUST (2004), DRIVER ET AL. (2011)
Connecting with the public	RUST (2004), DRIVER ET AL. (2011)
Connecting with stakeholders	
Connecting with the academic community	

Table 8

← ↑

Table 7 and 8
Summary of contributions and benefits in relation to the literature

● Findings in this research

and clear visual artefacts can catalyse collaboration by improving the research's accessibility. Moreover, one researcher even mentioned the possibility of designers helping to engage the public in the scientific knowledge production process, as they discussed co-design methods during a collaboration. When all these aspects are considered, a case can be made that design has the potential to play a role in building socially robust knowledge, as well as increasing interdisciplinarity and reflexivity within scientific frameworks (Gibbons et al., 1994; Nowotny et al., 2001, 2003). Furthermore, it can be argued that designers are generally well equipped to work at the interfaces of disciplines (Lawson, 2006).

BARRIERS AND FACILITATING FACTORS

Barriers

In subchapter [5-3] I described the many barriers that can affect the collaboration between designers and scientists. Across them, a few themes can be identified. One is the tension between disciplinary identities and interdisciplinary competences (Gibbons et al. 1994). Scientific disciplinary cultures influenced the collaborations greatly, as norms about knowledge production and representation, hierarchies and principles of scientific reduction (Janssen & Goldsworthy, 1996) affected the process. Moreover, design's validity as a discipline can be undermined in this worldview as it can be seen as superficial or decorative. Closely related is the lack of interdisciplinary competences, such as the ability to communicate across disciplines and to handle interdisciplinary collaboration.

Secondly, is the lack of knowledge about design and its methods, processes and outcomes. This affects expectations about collaboration and the design process itself. It seems that it is difficult for scientists to understand and for designers to communicate what is design. It is especially challenging to articulate the abstract and intangible nature of design (Kimbell, 2011). This is tied to the historical fragmentation of design as a discipline and to the variety of existing conceptualisations, as explained in subchapter [2-3] section [Defining design]. Moreover, I observed how designers struggle to "prove their value", a difficulty which is also noted in the private sector. Recent studies, such as those by the UK Design Council and McKinsey, have tried to address this.

A third barrier is found in organisational structures, particularly those of the university and the funding agencies. As previously described, there is a need for reconfiguring such structures to account for new paradigms of knowledge production (Gibbons et al., 1994; Nowotny et al., 2001, 2003). Although Aalto University has been working towards this goal, it seems that there are still many obstacles. The existing systems that allow and promote such endeavours are not necessarily integrated in the main structures of the university, which very much rely on disciplinary organisation. This issue becomes especially apparent with funding systems (as seen in subchapter [5-3] section [Structures]).

Finally, there is the question of resources. Time and budget are influential aspects that often reveal the previously mentioned barriers. It appears that issues around resources are often related to disciplinary culture, lack of knowledge about design or organisational structures. For example, not prioritising (in terms of time and funding) visual knowledge production can be traced back to disciplinary ideas of what constitutes valid knowledge. Alternatively, not investing in design could be connected to a lack of knowledge about its processes and value, or again, the difficulty to fund designers' positions can be related to the structures of the organisation.

Facilitating factors

Overall, it seems that elements which facilitate and enable science-design collaborations are similar to those found in studies about interdisciplinary collaborations in general. Some of these characteristics, which emerged in this research as well, are a positive and open-minded attitude, attention to language and communication, time and physical proximity (Epstein, 2005). In addition to these, the topic of the participants' stakes in the collaboration was identified. As described in subchapter [5-4] section [Mutual benefits and stakes], being mindful of the needs of all parties was an important element for a fulfilling collaboration. Therefore, acknowledging the existence of different agendas and finding a common ground between them appear to be difficult but necessary tasks.

MODELS OF COLLABORATION

The two models of engagement and positioning of design within the scientific research process were useful to facilitate the interviews and to reflect on the present situation and future possibilities. They showed clearly that in a large number of cases, design was seen as an *external resource*, positioned at the beginning or the end of the research process. However, while being useful conceptual and exploratory tools, the models of engagement also presented limitations. Most notably, they failed to highlight differences in approaches to multi-disciplinarity. They were focused on the relationship of designers to scientific research teams and their process, rather than on the relationship of design and science as disciplines. Moreover, the definition of team was sometimes questioned, as it was perceived differently by different people.

At the same time, the models of engagement prompted interviewees to express their interest in "deeper" integration, that is designers being a more *central* or *integrated* part of the team and contributing earlier in the process of research. *External resource* projects are sometimes seen as entry points for more design integration further on, for example in a possible future collaboration with the same scientist. While few of the participants experienced greater design integration and some only wished for it, it seems that the deeper the integration, the higher is the possibility to tap into inward and outward benefits. This seems especially true for inward benefits, for example, facilitation of research. However, since most of these thoughts were speculations on the interviewees' part, the benefits associated with deeper models of integration merit further investigation.

6 - 2
Implications

The findings of this thesis are relevant for researchers concerned with collaboration between design and science, as well as researchers, designers or research managers interested in establishing said collaborations. For those studying the potential use of design in other fields, it provides an empirical account that contributes to an existing body of literature. Moreover, it sheds light on a little studied phenomenon, that of design's role in the scientific research process. While confirming findings in the literature, new contributions and benefits of integrating design are highlighted as well. Furthermore, this research points to areas which could be explored further, as described below [6-3].

For practitioners, this thesis highlights lessons learned in a leading design and research university to better understand, communicate and plan collaborations. Firstly, it provides a vocabulary for describing design-science collaborations, which can aid in articulating the role of designers and the benefits of their contributions. Secondly, insights into the models of collaboration can support the structuring and planning of collaborations. Finally, raising awareness of the obstacles and enabling factors points to aspects that need to be addressed to achieve more successful collaborations. Especially at strategy and management level, organisational structures, knowledge about design and interdisciplinary competences are highlighted as relevant areas for investigation. Additionally, similarities have been found between the issues related to integrating design in the scientific research process and in other contexts, such as the difficulty of proving the value of design. These connections could be explored to draw insights into practical solutions and effective practices.

6 - 3
Limitations and further research

As Aalto University has a large science and technology research core, the contribution of design was observed within science and engineering disciplines. Collaboration with designers in the context of scientific research in other domains, such as the social (e.g. anthropology, sociology) and formal sciences (e.g. mathematics, statistics), remains outside the scope of this study. Moreover, Finland and Aalto University represent favourable settings for the integration of design, as seen from the University Strategy to the general interest in design throughout other sectors of society, including government and the thriving business and start-up culture. At the same time, contexts in which the integration of design is less favoured and developed might present different challenges, and while some of the findings of this thesis could be valid in other contexts, further research should be conducted.

As this research focused on the experiences of people participating in design-science collaborations, the group of interviewees whom I had access to and who were willing to share their point of view were the ones who generally had positive experiences. This is true especially for the scientists, since the designers, who worked with different researchers, usually had a range of positive and negative experiences. Although the cases presented a variety of outcomes, they were mostly favourable, and consequently a positive bias needs to be acknowledged. Furthermore, the study focused on those who were involved first-hand in the collaborations. Therefore, the perception of design among scientists with no previous experience was not explored. However, it would be beneficial to understand the perception of design within scientific disciplines through further research.

Finally, few instances of deeper integration could be observed, and for this reason most cases figured a brief or “light” integration of design. The benefits and qualities associated with deeper integration are still mostly unclear and would require more research. However, for interviewees who wished for or who had experienced more integration of design in the scientific process, several interesting topics emerged that show potential for more investigation. One is the possibility of design informing the scientific research process at a strategic level. Such a possibility is compelling as it would reflect a similar trend in private and public organisations in terms of integrating design, and in the discipline of design more generally. Finally, this study has shown that, as scientific institutions are feeling the pressure to change, design can, in the right conditions, potentially have a role in the development of socially robust knowledge, as well as in increasing interdisciplinarity and reflexivity within scientific frameworks.

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Appendix

A

Consent form and privacy notice

CONSENT TO PARTICIPATE TO RESEARCH STUDY FOR MASTER'S THESIS
Research participant of Ada Peiretti's Master's Thesis fills out

I have understood that participation is voluntary and at any point in the research study, I am at liberty to notify that I no longer wish to participate in the study, but all the information gathered up until that point is can be used as described in the privacy notice of the research study.

I have received sufficient information about the research study, I have had the possibility to have my questions answered, I have understood the information and I wish to participate in the research study.

I give permission for the interview to be audio recorded.

I understand that the interview content may be used and published by Ada Peiretti for her Master's Thesis at Aalto University.

Anonymity preferences: for publication, I allow the following to be used:

[YES / NO] My name. If no, I understand that content and quotations from my interview may be used, but without my name or disclosing information that reveals my Identity.
[YES / NO] My organisation's name. If no, I understand that a pseudonym will be used in place of my organisation's name, without disclosing information that reveals my organisation's identity.

I agree to participate in this research by signing this consent.

Date ___.___._____

____
Signature and name of research participant
(choosing to participate can be also expressed electronically)

Contact details:
Ada Peiretti
ada.peiretti@aalto.fi
+358 40 322 0878

PRIVACY NOTICE FOR ADA PEIRETTI'S MASTER'S THESIS

1. Purpose of the research study
This study maps and analyses examples of emerging practices of collaboration between designers and scientists in visualising scientific knowledge in the context of Aalto University. The goal is to identify potential roles of designers in the process of science communication and scientific work and to describe the challenges that come with integrating such roles.

The research is supervised by Eeva Berglund, Adjunct Professor (Environmental Policy), Department of Design.

2. Participation is voluntary
Allowing use of the issues discussed during the interview is voluntary. Participation can be discontinued at any time by contacting Ada Peiretti. Should you discontinue to allow the use of your information, you will not be subject to any negative consequences, but information gathered until the point of withdrawal may be used in research.

3. How data is collected?
Research on the case study includes interviews with participants and archival sources such as project websites, articles, press releases, promotional content.

4. How data is used
Data is used to map the emerging practices, to analyse the process and describe the challenges of such collaborations and the potential contributions of design.

5. Legal basis
We do not expect the processing to affect data subjects in any way. The research study aims to identify potential roles of designers in the process of science communication and scientific work and to describe the challenges that come with integrating such roles. The legal basis for processing personal data is the consent of the data subject. The legal base of publications is academic expression.

6. The rights of the study participant and the exercising of your rights
The data subject is the participant of the master's thesis research study.
The data subject has the following rights during the research and analysing of the material:

- The right request access to data
- The right to object to processing the data
- The right to rectify information
- The right to request restricting of processing

Because data is being processed for the purposes of scientific research, the data is not used in decision-making related to the data subject.

7. Sharing of Personal Data
The supervisor(s) for academic verification.

8. Measures taken to protect your data
The following measures are taken in this research study to protect your rights:

- The research study has a research plan.
- The person responsible for the research study is: Ada Peiretti
- The supervisor of the research study is: Eeva Berglund

9. Storage period of your data and anonymisation

The criteria for defining this period is based on good scientific practice. In scientific research, the aim is to store the research data so that the research results can be verified.
Anonymised data is no longer personal data. Raw data is stored by using Google Drive (managed by aalto.fi) and personal hard drive.

10. The Controller
The controller in this study is Ada Peiretti.
Contact information:
ada.peiretti@aalto.fi
+358 40 322 0878

The research data subject can contact Aalto University's Data Protection Officer if they have questions or demands related to the processing of personal data, phone number: +3580947001, Email: tietosuojavastaava@aalto.fi

If the research data subject sees that their data has been processed in violation of the general data protection regulation, the data subject has the right to lodge a complaint with the supervisory authority, the data protection ombudsman (see more: tietosuoja.fi).

B

Interview plan and visual probes

INTRODUCTION

- Introduce myself
- Introduce thesis topic and motivation:
  This study maps and analyses examples of emerging practices of collaboration between designers and scientists in the process of scientific research in Aalto University. The goal is to identify potential roles of designers in the process of knowledge production and to describe the challenges that come with integrating such roles.
- Explain why I want to interview this person and that I have a guide just to help me cover some key questions
- Hand them consent form and privacy notice
- Ask permission to record the interview
- Highlight freedom to ask questions and refuse answering any questions

WARM-UP

- Tell me a bit about yourself and the work you do in general
- Tell me about the science-design collaboration you are/have been involved in
- How did this work come about?
- What institutions/structures supported it?

PROCESS AND ROLES

- Can you briefly describe the process of designing in collaboration with scientists/designers?
- What are the steps?
- When does design come in?
- Do you see this process as part of scientific work or not?
- In your opinion, what is the role/roles of the designer in such process?

CHALLENGES

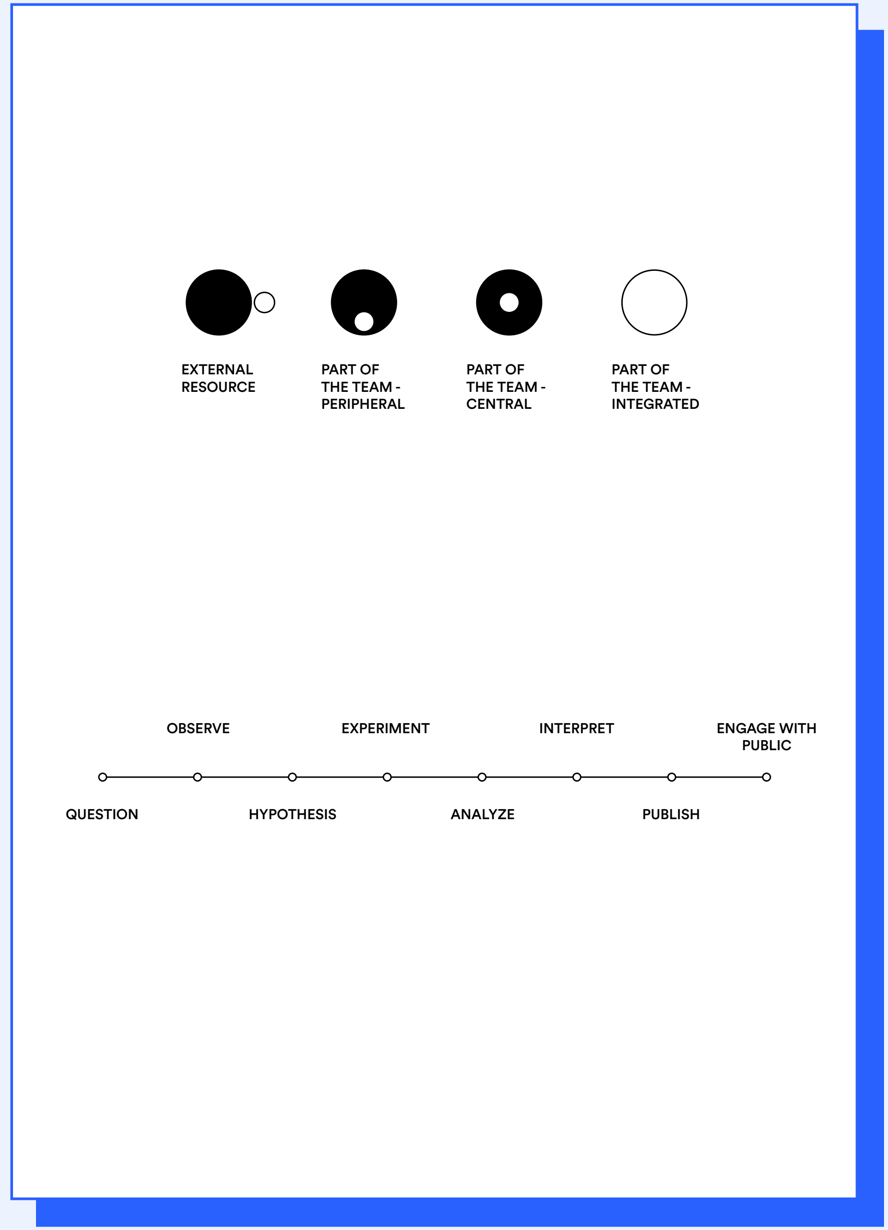
- In your opinion, what are the biggest challenges in these collaborations?

POTENTIAL

- In your opinion, what is the biggest potential of these collaborations?
- What do you see as the main contribution of introducing design in the scientific practice?

WRAP-UP

- Do you know of other similar experiences?
- Do you know of anyone else involved in such collaborations who might be interested in participating in this study?
- Can you share some images, or are there any in the public domain already?



C
Coding scheme

Coding Scheme

Main category	Codes	Description	Reference
1 Contributions	1a Visualising knowledge	Visualising scientific ideas, communicating complex knowledge	Rust (2007), Driver et al.(2011), Cheng at al. (2017)
	1b Designerly ways of thinking	Contributions related to the thinking process of designers, strategic and systemic thinking	
	1c Design methods	Mention of integrating specific design methods	
2 Benefits	2a Connecting with public	Connecting with non-scientists, helping disseminate knowledge to the general population	Rust (2007), Driver et al.(2011)
	2b Connecting with academic community	Expanding the reach and impact of scientific research within the academic community, collaborating with other disciplines	
	2c Connecting with stakeholders	Improving communication and reach towards industry partners and funding institutions	
	2d Facilitation of research	Facilitating the advancement of scientific research by providing means of experimentation and reflection	Rust (2007), Driver et al.(2011)
	2e Challenging perception	Challenging the scientist's perceptions and encouraging the pursuit of new research directions	Rust (2007), Driver et al.(2011)
3 Barriers	3a Time	Time available doesn't match tasks, timing is off, time is not enough	
	3b Budget	Budget is insufficient, difficulty to fund collaboration	
	3c Lack of trust & communication	Inability to communicate effectively, misunderstandings, lack of mutual trust	
	3d Different discipline ethos & language	Lack of common ground and language, different ways of working, challenges to disciplinary identity	Rust (2007), Driver et al.(2011) [*shared formal language*]
	3e Familiarity & expectations	Lack of knowledge about the processes of design, misplaced expectations	
	3f Structures	Hindering structural elements, bureaucracy, funding/hiring procedures	
4 Facilitators	4a Positive and open-minded attitude	Open minded people, receptive to input, open to learning	Epstein, 2005
	4b Time and trust	Proper time is given, long-term collaboration, building trust	Epstein, 2005
	4c Mutual benefit and stakes	Both parties gain something, collaboration is useful for everyone	Epstein, 2005
	4d Institutional support	The university or other organisations supporting the collaboration	Epstein, 2005
	4e Physical proximity	Practices of working together face-to-face	Epstein, 2005
5 Activities	5 Activities	Information related to ways of working in the projects, practicalities	
6 Models of collaboration	6 Models of collaboration	Discussion around the visual probes	

Aalto University